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PROMINENT MEMBERS OF THE FRANKLIN INSTITUTE. No. 4. COLEMAN SELLERS. 1827–1907.

BY

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Coleman Sellers was a notable example of a man who upheld a family tradition. His progenitors for at least five generations were men of marked mental ability and mechanical aptitude. His paternal grandfather, Nathan Sellers, a surveyor and conveyancer, had marched off to join Washington's troops in time to take part in the Long Island campaign. He was a man of many parts whose ability, like that of so many contemporaries, was not confined within a single channel. His skill in making the deckle wires required in papermaking was almost unique, so that his absence on military service proved to be a severe handicap to the paper industry. The papermakers were led to petition Congress to release him in order that he might devote his time to satisfying their needs. The reliance of Congress upon the issue of a paper currency probably helped to secure his recall.

His grandfather on his mother's side of the family was Charles Wilson Peale, the gifted painter and naturalist, from whom he may have inherited some of the artistic qualities that distinguished his work.

Coleman Sellers senior was also a mechanic of marked inventive ability. Working with George Brandt of the Columbia and Philadelphia Railroad, he invented a system of counterbalances which offset the disturbing forces that made a locomotive hard on the tracks. This was later developed by his elder sons, Charles and George Sellers. Their design was universally adopted and it became an essential part of the American type of locomotive. The younger Coleman was deprived of any influence his gifted parent might have exercised, for his father died when the boy was only seven years old. However, some of his mechanical talent appears to have been transmitted to his son.

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Born in Philadelphia January 28, 1827, and dispossessed of his father's guidance, young Coleman had the good fortune to have a mother who was a lady of understanding and aptitude, well qualified to supervise the upbringing of an extraordinary son.

Mrs. Sellers had perceived the strong practical strain in the boy's mental attitudes, and she had projected a farmer's life for him. As this required that he should become self-reliant, it was her hope that he might cultivate whatever talent he had in that direction. There were, of course, no facilities for obtaining vocational training in those days, but Mrs. Sellers was so determined that her son should supplement his education with a course of manual training that she devised a program of her own by which he could develop the skill of his hands (1).[2] He was to offer abundant proof that this laid an excellent foundation for his subsequent activities.

Formal education was not neglected. At the age of eleven, the young Coleman entered Anthony Bolmar's Academy at West Chester, Pa. The curriculum included elementary studies in natural philosophy, as the science of physics was called in those days, and the simple experiments he saw performed to illustrate the physical principles acted as a stimulant to his interest. At the age of fifteen he made an entry in his diary which showed his interest in meteorology.

> Thursday, November 3rd, 1842. Began to make a hygrometer; it is made of catgut on which the atmosphere acts, expanding and contracting it, thus moving an index which shows the degrees on a plate. I have been thinking of making one with a piece of ash, which, by expanding and contracting, works compound levers which are joined to the index; thus by a slight difference in the wood a great difference will be perceived in the position of the index; it is to be made on pretty much the same principle as those instruments which show the expansive power of metals, only instead of metal a piece of ash is used in the body of the thing to be expanded, and instead of being acted upon by the heat it is acted upon by the atmosphere (2).

Having had a night to cogitate upon this device, he conceived a way of improving it. He had projected using a weight, as was customary in making a catgut hygrometer, but upon reflection he proposed to replace this with a spring so that the instrument could then operate in any position, whereas the use of a weight ordained that the instrument be always perpendicular.

The ideas were there, but the incipient inventor was prevented from carrying them out because he had to lament the lack of suitable tools to perform the work.

The diary contains some insight into the youth's precocious scholarship, which foreshadowed the accomplished technician. Within a week of the entry quoted above he records having begun the study of trigonometry and finds it "pretty easy," a judgment that could be shared by few modern youths of his age. He was also reading Scott's *Waverley*

[2] The boldface numbers in parentheses refer to the references appended to this paper.

novels with enjoyment, and was contemplating the construction of a device to demonstrate that "if a weight is dropped from the masthead of a ship in motion it will follow a diagonal course in its descent and would fall at the foot of the mast."

His hunger for knowledge was not satisfied by the lectures of the local physician, who was the Academy's science instructor. There was apparently an insufficiency of experimental work, for Sellers spent a great deal of his time in planning and constructing apparatus for demonstrating the application of the slender theories presented in the classroom. It was evident, too, that he was trying very seriously to prepare himself for the role of the complete farmer he was intended to fill, for he began to study botany and mineralogy. Progress in these studies was unsatisfactory also, for he complained he could not obtain the books he needed to advance his knowledge.

Six years at Bolmar's Academy completed his formal education and, in accordance with his mother's plans, he went to work on a nearby farm. As might be expected this occupation failed to suppress his yearning for mechanical pursuits, for his inventive faculty proved irrepressible. Farming was not yet a large-scale operation and the need for the invention of mechanical implements had not yet been felt, otherwise agricultural technology might have exercised a greater attraction for young Sellers. His only contribution to this field was a metal-toothed hayrake mounted on wheels to facilitate labor in the fields. This was an anticipation of the machine now in general use.

At this time, his elder brothers Charles and George were operating the Globe Rolling Mill in Cincinnati. Probably from sympathy for the young Coleman, and to give freer rein to his mechanical bent of mind, they made him an offer of employment in the mill. In 1846, at the age of nineteen, he was allowed to accept the offer. On his arrival he was assigned to the preparation of drawings for improvements to be made in the machinery operating in a mill owned by Horatio Allen, of the Novelty Iron Works, New York. When this work was completed, Coleman embarked upon the acquisition of a comprehensive knowledge of all the processes involved in the rolling of iron, wire rods, and the flat rails used at that time on the western railroads. He accomplished this by working in the different shops.

The Globe Mill had a subsidiary mill in which Coleman perceived the need for improved machinery. The electric telegraph had reached Cincinnati in 1847 and steps were being taken to extend its use. Coleman perceived there would be an increased demand for wire and he wanted to see the plant efficiently equipped to meet the needs he could discern. While engaged in this work of making telegraph wire he made the acquaintance of Henry O'Reilly, whose vast projects earned for him the title of "Telegraph King of the West." This acquaintance ripened into a close friendship that was to prove valuable to the younger man.

O'Reilly was familiar with the work of Joseph Henry and Michael Faraday in electromagnetism and he possessed the necessary apparatus for repeating some of their experiments. As the acquaintance developed, Coleman borrowed some of O'Reilly's equipment which he employed in the performance of the classic experiments. It is obvious that he gained a great deal of proficiency in the science, for he constructed an instrument from his own design to demonstrate the tangential force of magnetism (3). Thus, he laid the groundwork for his wide knowledge of the electrical science which was to furnish him with the major triumph of his fruitful career.

The young Sellers was also employed upon the survey of the Covington-Lexington Railroad, later to be known as the Kentucky Southern. By the time he had reached the age of twenty-one his abilities were so well-pronounced that his brothers promoted him to the position of general superintendent over the Globe Mill. The brothers were contemplating the enlargement of their operations, and two years later, Coleman was building locomotives designed by his brothers for the Panama Railroad.

His time in Cincinnati was not exclusively occupied by mill affairs. He was a young man of gregarious habit and found leisure for social activities of a serious nature. Sellers had that personal magnetism which attracts other men. Even at this early age he was the center of a group of thoughtful companions who met to discuss the philosophical and scientific problems of the day. We learn of him expounding electrical theories and demonstrating the electrical discoveries as they were announced. At one of their meetings they plunged into metaphysics to discuss Swedenborg's *Principia*, and Coleman took an active part in the discussion. He also made many excursions into the limestone hills near the city, renewing his earlier interest in botany and mineralogy. The hills were rich in fossils, for which he searched enthusiastically, and was rewarded by finding some perfect specimens.

There was leisure, too, for more lightsome social distractions as is evidenced by the fact that, in 1851, he was married to Miss Cornelia Wells, daughter of a local family.

Later in the same year he entered the employment of James and Jonathan Niles, as superintendent of their locomotive works in Cincinnati. The experience he gained during the five years he occupied this position convinced him of the need for improving the machine tools required for work of this nature. In 1856, he left this occupation in order to return to Philadelphia where he joined his kinsmen in the firm of William Sellers & Company. This firm had a well-established reputation. "By the engineering ability they have displayed they are entitled to rank among the most eminent of European and American engineers" was a contemporary opinion (4).

Entering the firm to take charge of the draughting room, Sellers soon

made his mark and passed through various other positions to arrive eventually at its chief executive post. For a period of thirty years his fertile mind grappled with a diversity of mechanical problems embracing machine tools, hydraulic machinery, cranes, hoists, presses, pumps, injectors, railway turntables, and many other machines.

Morton, a well-qualified authority, says that Sellers' work was characterized by originality, correct mechanical design, and unusual elegance of outline (2). His originality is attested by the long list of patents issued under his name. From among these might be selected for mention the double cone coupling for shafts, which was the first successful substitute for the flange or plate coupling. The flange coupling had to be pressed on the end of the shaft, a process that called for slow and careful finishing to achieve the proper dimensions. The Sellers' coupling would tolerate a considerable variation in size, and would grasp the two shafts with equal force and maintain correct alignment, even when there was an appreciable difference in the diameter of the shafts to be coupled. This invention introduced a radical change in the manufacture of shafting, reducing the cost of production and greatly simplifying both installation and maintenance. It opened up new avenues of approach to the whole problem of shafting and was the basis of many other improvements in that field.

Each change of occupation had heralded a new development of correlated study. Farming had induced the incubating inventor to develop the metal rake; drawing copper wire had led to the investigation of electrical installations in which it was applied; and now an assortment of problems passing over his desk found him meeting a diversity of subjects with equal facility. He even entered the field of publicity.

In those days the illustrations in the firm's catalogues were mostly ambrotypes. These did not satisfy Sellers' fastidious taste, nor did they present effectively the beauty of the machines in which he took so much pride. Resolving to improve the character of these pictures and to have the best possible, he determined to learn what photography could accomplish in this line. He was acquainted with the elements of the art, but he set about acquiring a proficiency in it. Before long he had installed a dark-room in the draughting department, and the apprentices were being instructed in taking, developing, and printing photographs. Pictures of machinery were not his sole objective. He was soon immersed in portraiture and his love of outdoor life induced him to make photographs of landscapes. His devotion to outdoor work with the camera inspired him to seek improvements in some features of the work that were attended with such difficulties that they discouraged many amateurs.

Field work with the wet plates then in use rendered difficult the necessity for keeping the plate wet between making the exposure and developing the plate. This implied that the photographer had to

carry his own water supply. Sellers found a way out of this inconvenience by coating the plate with a mixture of glycerine and water, and keeping it shut up in a light proof box. This deferred the need for washing until a convenient time, perhaps a month later.

Another bug-bear of the photographer arose when he wished to change his plates. Sellers earned additional gratitude from his photographic friends when he contrived a simple portable dark-room which facilitated the change.

Although his interest in photography was not aroused until 1858 he made such rapid progress in the art that he was a frequent contributor to the American photographic journals during the years 1861–62. He was so highly regarded as a representative of American photographers that he was selected to act as correspondent for the *British Journal of Photography*. He was one of the founders of the Philadelphia Photographic Society.

It is a tenable supposition that it was Sellers' desire to be able to show the machines in motion by photography which served as the impulse for his next notable achievement. In 1861, he applied for and was granted a patent upon a device which he called the "Kinematoscope" (5). This was the earliest machine for viewing photographs depicting objects or people in continuous motion. This prototype of the modern motion picture apparatus is exhibited in The Franklin Institute Museum, the gift of his sons. This crude device displays motion in its simplest forms due to the limitations of the wet plate process, by which instantaneous photography was impossible, but the inventor foresaw that photography would undergo much improvement, and he anticipated the appearance of the continuous roll of film for motion picture projection by suggesting that the pictures should be mounted on a continuous flexible belt.

The original machine contributed the word "kinema" to the science, a term that was to be universally adopted. Sellers displayed a thorough grasp of optics in the methods he adopted for attaining two vital factors in the reproduction of motion by pictures. First, was the need for bringing the separate pictures to rest during the moment of vision, and the second was that which held the pictures intermittently before the eye long enough for the eye to register the picture sufficiently to enable the retina to retain the impression.

The Kinematoscope was only the first step in the science of motion picture photography. It lacked the essentials of enlargement by projection on a screen for exhibition to a large audience, and it could be viewed only by one pair of eyes at a time. It should be observed that these two features were not regarded as essentials by Edison, who is generally credited with the invention of the motion picture. He opposed its projection to an audience for commercial reasons and only pressure of competition compelled him to adopt these essentials.

Sellers realized the limitations of the Kinematoscope and he made no effort to commercialize it. Although it has been asserted (6) he regarded it only as a form of amusement there is little doubt that he anticipated making improvements as a means of demonstrating the firm's machines in operation, for, in his patent application, he states the object of the device to be to "exhibit stereoscopic pictures as to make them represent objects in motion, such as revolving wheels in machinery."

Another science into which his occupation conducted him was microscopy. In the course of his business he was confronted with the problems presented by the formation of a stoney deposit or scale which formed inside steam boilers. It seemed to him that the microscope might reveal some unsuspected feature in the scale. He collected a number of specimens which he ground to a transparent thinness for investigation by polarized light, a method which had recently been discovered by Vogelsang and Zirkel. Having acquired a skill in the preparation of thin sections of solid substances he made an attractive series of slides, specializing in diatomaceous earths. Then he extended his researches to the fresh water algae.

He was ingenious in his methods of overcoming what was difficult to other men. In order to facilitate his work in microscopy he devised interesting means of improving the instrument. His success in these studies aroused the interest of his friends with whom he wished to share the satisfaction of his results. He thereupon arranged to show some specimens by lantern projection. To do this he required oxygen for the operation of the projector, but as there was no commercial source of supply for this gas, the undismayed Sellers made his own supply.

It must be reasonably obvious that to extend his professional activities into the pursuit of so many sciences and intellectual pastimes, Sellers did not draw any fine line between work and leisure. Those hours which a busy man of affairs would have devoted to rest and relaxation were consumed by Sellers in extending his knowledge of man and nature. It would be a mistake to assume that he was interested solely in things. He was keenly interested in ideas. He took a deep interest in philosophy and on one occasion he delighted an audience with his examination of Sir William Crooke's *Psychic Force*. But he was a born experimenter. He delighted in repeating experiments of unusual interest, and he never hesitated to conduct his own experiments when the literature on the subject failed to furnish him with the information he needed.

At a later date he had to know what effect the action of swiftly flowing water would have upon the material from which the Niagara Falls power tunnel was to be constructed. Moreover, he had to have the information quickly. Rather than submit the tests to an outside source, with inevitable delays, he set up apparatus in his home by which

a measured quantity of sand could be forced at constant pressure against the substance under test. He was thereby enabled to tabulate the relative effects of abrasion on brick, concrete, stone, cement, and other materials, as measured by the loss in weight of the specimen.

His associates frequently spoke of Sellers' unusual ability to devise working models or apparatus for the solution of engineering or physical problems arising in the course of his work.

Allusion has been made to his early association with the telegraph during the days when he was making wire. He was quick to perceive the time-saving that could be effected through the medium of this device, and he installed a system of inter-office communication throughout the dispersed departments of the firm.

As a youth he had been a member of the Cincinnati Mechanics Institute, and he made a point of attending meetings regularly. Here he gave his first lecture. Sellers possessed a rare sympathy for imparting knowledge. He was always ready to place his own store of experience and knowledge at the service of the less gifted, and he excelled in that happy faculty of making a complicated subject clear to a learner without impressing the pupil with a feeling of inferiority. He was invited to lecture before several organizations on technical and philosophical subjects which interested him. Soon after his return to the neighborhood of Philadelphia in 1858, he began his long association with The Franklin Institute. He threw himself with zest into its labors and so earned the respect of his fellow-members that he was appointed to committee work. His remarks upon the papers read at the Institute meetings were awaited with interest by the members present, and his own papers on mechanical matters were valuable contributions to the subject. For twenty-three years he was Professor of Mechanics in the Institute's technical school, where the students learned to appreciate his ability to explain difficult points in a simple manner. It became apparent that, in addition to the qualities of a successful business executive and practicing engineer, he possessed those of the born teacher, a fact that was proven by the many tributes paid him by his former students.

His relations with his fellow-members of the Institute were of the happiest character. Numerous stories were told of his ingenuity displayed for the benefit of the members. One of the more interesting of these was related by a witness who described it in a letter to one of Sellers' relatives.

> I was in the office of the Secretary of the Institute when an inventor was showing to a group of engineers a so-called "unpickable" lock, the peculiar feature being that there was no visible keyhole. The lock was fastened to the underside of a highly polished steel plate about seven by eight inches; the upper surface was engraved with fine lines resembling the pattern of watered silk. After careful scrutiny the men all declared they could detect no means of finding a keyhole. The inventor then produced a small horse-

shoe magnet which, he said, was the only possible "open sesame." Placing the magnet on the plate near the middle, he drew up a piece of the steel plate the size of a keyhole, and that had been so skillfully mitered in, following the engraved lines, that it escaped all observation. The inventor said that unless the burglar had a similar magnet he could not withdraw the mitered piece. This was considered quite ingenious.

Just then, Dr. Coleman Sellers happened in, after the mitered piece had been restored to its place. Dr. Sellers took a small magnifying glass from his pocket, examined the plate, and said to me: 'Outeridge, will you please go downstairs to the laboratory, where you will see a long piece of light steel spring from an old clock. Cut off a piece of about four inches long and bring it to me with a piece of beeswax you will find in a drawer of the work-bench. I quickly did this. Dr. Sellers bent the spring into a bow, fastened a little piece of beeswax in the middle, pressed it down on the spot where the inventor had previously placed his magnet, and up popped the mitered piece of steel, causing quite a sensation. The inventor was evidently chagrined, for he picked up his lock and walked out.

Dr. Sellers explained that by the aid of his magnifying glass he detected at once the mitered piece of steel, and took a chance that the beeswax would stick and the spring would be strong enough to raise the piece from its seat.

Sellers' work for the Institute, his enthusiasm for its welfare, and his own abilities were recognized by the members, who elected him to the Board of Managers in 1862. He was President during the years 1870–74. At the ceremonies attending the celebration of the Institute's 75th anniversary, he was awarded the honor of election to the select band of Honorary Members.

In 1884, the University of Edinburgh celebrated its tercentenary and Sellers attended the ceremonies as the delegate of the Institute. As this was his first acquaintance with Europe, he seized the opportunity of making an extended tour which embraced the British Isles, France, Germany, Sweden, and Norway. He had been so attracted by what he had seen of the Scottish Highlands that he returned two years later for a prolonged summer holiday. His health was no longer robust and, while he benefitted from his holiday, he determined on his return home, that he would retire from active participation in William Sellers & Company but, as he did not feel his energies were entirely exhausted, he decided to retain contact with his profession by opening practice as a consulting engineer.

It is a singular comment upon the mutability of human affairs that his greatest achievement should have come after his withdrawal from active business. Blissfully unconscious of what the future had in store, he continued to teach mechanics at the Institute. His reputation as an instructor was so well established that, when the Stevens Institute of Technology founded the chair of Engineering Practice, it was immediately offered to Sellers, who accepted it on conditions that he might serve as a non-resident member of the faculty. The purpose of this foundation was to furnish students with a better knowledge of the ways to apply their theoretical instruction, and to bring them into contact with the problems, customs, and requirements of practical engineering. Sellers was admirably qualified to hold this chair. Indeed it was not

long before his lectures were being attended by other members of the faculty, who wished to profit from the study of his methods.

He was called away from these academic occupations to undertake the task that was to be a fitting climax to a brilliant career. This was the completion of the project for harnessing the force of Niagara Falls and converting it into electrical power. The extent to which the judgment and painstaking investigations of Coleman Sellers influenced electrical development in the United States along lines now well established has not been recognized.

In October, 1889, Sellers was engaged by the Niagara Falls Power Company to report upon the engineering problems confronting the company. The project had been conceived by Thomas Evershed, engineer of the Erie Canal, who had proposed installing turbine wheels about a mile above the Falls. These turbines were to discharge into a tunnel that would have its outlet on the river bank below the Falls. Legislation had been passed to promote the scheme but financiers were unwilling to underwrite it until expert opinions had been obtained that would approve of the project and would offer assurance of a profitable utilization of the electrical power produced. It had been proposed to utilize the water power for generating electricity that would be transmitted to Buffalo (7).

Sellers was engaged to "investigate the conditions and advise as to the development of power and to consider the relative merits of the systems available for local and distant use, the extent of their commercial applications, etc." The choice of Sellers for this task was most appropriate for, as we have seen, he brought to the consideration of the problems a judgment trained by many years of active and varied engineering experience. The report he presented to the directors showed how the project might be developed with profit. As it also encouraged the financiers to afford it their support, it was decided to carry out the plan Sellers had recommended under his personal direction. He was then appointed Chief Engineer of the scheme.

In 1890, the Company appointed the International Niagara Commission, authorizing it to award prizes to the value of $22,000 for plans for the generation of power by water, and its transmission to a distance by an economic method. The International nature of the Commission was demonstrated by its composition, the members being Lord Kelvin (British), Professor Elie Mascart (France), Dr. Theodore Turretini (Switzerland), and Coleman Sellers. Professor C. Unwin of London acted as secretary, and the commissioners were to meet in London.

In those early days of electrical engineering applicable theory was in its infancy, while practical precedent on a comparable scale was nonexistent. As an example of the limitations of knowledge under which the members of the Commission labored one might quote the disagreement upon the use of alternating current. Lord Kelvin, an interna-

tionally esteemed physicist, proposed the exclusion of all systems of electrical power transmission other than direct current systems. This would have placed a fatal handicap upon the whole scheme, as direct current was limited to low voltages and was not adaptable to the production of widely different voltages within the same system. In the light of our present state of knowledge an exclusive preference for direct current may appear short-sighted, but it should be remembered that the competitive system encountered strong opposition from those companies (who had the support of Thomas Edison's opinion) already in existence and were wedded to the distribution of direct current. Their most devastating argument centered around the danger of electrocution involved in the use of alternating current. Only a few scientifically minded men realized the falsity of this assertion and maintained their interest in alternating current.

Sellers was one of the more enlightened men who declined to allow their judgment to be confused by commercial intrigues. He wisely adopted the attitude that the Commissioners' knowledge of the potentiality of alternating current was not sufficient to justify action that would exclude it from all consideration. He had been closely associated with Elihu Thomson in The Franklin Institute, and was the life-long friend of George Westinghouse (**8**), the two principal exponents of the use of alternating current. He was more fully informed of its potentialities than the other Commissioners, and he fought stubbornly in its defense. Fortunately, his opinions prevailed to secure the adoption of alternating current after he had seen the Westinghouse polyphase system demonstrated at the Columbia Exposition of 1893.

Preceding the meeting of the International Commission, Sellers had visited France, Switzerland, and Italy for the purpose of visiting the large hydraulic stations and studying their methods of transmitting power. Again, in the following year, between sittings of the Commission, he travelled extensively through France and Italy where he visited the principal engineering works. The knowledge he acquired from these visits was to prove of inestimable value when a decision had to be made upon a suitable system for the Niagara Falls Company.

Numerous firms and engineers were invited to submit plans for the utilization of Niagara's power. Twenty-two projects were submitted, only two of which came from the United States. It is noteworthy that neither of the two domestic projects were submitted by electrical firms, and that both contemplated the use of compressed air for the distribution of power. Since the plans offered were so widely divergent, and some heatedly advocated, much analytical and constructive criticism had to be exercised in order that the merits of each might be evaluated.

Even when the transformer was recognized to be the key to the problem of the transmission of electrical power, discordant voices were raised in advocating the claims of various voltages and frequencies.

When the company's electrical experts failed to reach agreement, Sellers had the responsibility for making decisions, a responsibility that extended to both the mechanical and hydraulic fields. A number of the important features of the first and second power houses at Niagara were the outcome of his ideas, for his inventive genius was radiated into many problems. Among the more important of his conceptions were the hydraulic governor improvements, thrust bearings, machinery for lowering and raising the gates, and some of the mechanical features in dynamo design.

It was not only his broad knowledge of physical science and his long experience in dealing with mechanical problems that was put to severe test during this period. His personal character played an important part in setting this, the first great electrical power transmission plant, upon the right path. His personal charm, his modesty, his conciliatory attitude to those with whom he disagreed contributed in no small degree to the solution of the problems confronting the Niagara Falls Power Company.

When we choose to recall the far-reaching effect of the example offered by this first power house and its influence upon the development of the art of electrical power transmission, we begin to realize the extent of the part played by Sellers in that field. We can see, too, that his success was founded as much on character as upon knowledge. As an engineer he earned the respect of his colleagues; as a man he won more than respect, he gained the affection of all who were admitted to association with him.

REFERENCES

(1) "In Memoriam: Coleman Sellers," JOUR. FRANKLIN INST., Vol. CLXV, p. 166 (1908).
(2) H. MORTON, "Coleman Sellers, E.D., Sc.D.," *Cassiers' Magazine*, Vol. XXIV, p. 352 (1903).
(3) *Ibid.*, p. 354.
(4) E. T. FREEDLEY, "Philadelphia and its Manufactures," Philadelphia, J. D. Anvil & Co., 1859, p. 313.
(5) U. S. Patent 31,357, February 5, 1861.
(6) H. CROY, "How Motion Pictures Are Made," New York, Harper Bros., 1918, p. 8.
(7) E. D. ADAMS, "Niagara Power: History of the Niagara Falls Power Company, 1886–1918," privately printed, 1927.
(8) H. G. PROUT, "Life of George Westinghouse," New York, Chas. Scribner & Co., 1922, p. 155.

MATRIX ANALYSIS OF HEAT TRANSFER PROBLEMS

BY

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ABSTRACT

This paper presents a method of analysis of heat conduction problems in solids based on matrix algebra. Use is made of the analogy that exists between the thermal problem and the flow of electricity in an electrical transmission line. It is shown that the use of matrix algebra greatly facilitates the calculation of transient and periodic heat flow in composite solids.

INTRODUCTION

The close analogy that exists between the flow of heat in one dimension and the propagation of electricity in an electric cable has been known for a long time (1, 2, 3).[2] During recent years, several electrical engineers and physicists (4, 5, 6, 7) have systematized the mathematical analysis of propagation problems along transmission lines and cables by the introduction of the concept of the four-terminal network or quadripole and by the introduction of matrix algebra for the systematic analysis of such networks. It is the purpose of this discussion to call these modern techniques to the attention of engineers who are concerned with heat-conduction problems. The basic principles involved are presented and their use is illustrated by applying them to representative problems.

THE FUNDAMENTAL EQUATIONS

Consider the simple case of a homogeneous rectangular slab of material of uniform thickness shown in Fig. 1. Assume that the heat losses at the edges of the slab are such that they may be neglected and that the temperature of the slab is a function only of the co-ordinate x and the time t. Introduce the following notation:

$e(x,t)$ = temperature of all points of slab situated at a distance x from edge of slab as shown in Fig. 1.

$i(x,t)$ = heat flux or quantity of heat that passes through a plane perpendicular to the x-axis at a distance x from edge of slab per unit area in unit time.

R = thermal or heat resistance per unit length of material of slab in direction of heat flow per unit area. ($1/R$ is thermal conductivity.)

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

C = heat capacitance of slab material. This is the number of heat units required to raise a block of the material of the slab of unit volume 1 deg in temperature. (C = specific heat, x density.)

Then, since Ri is the temperature drop per unit length along the x-axis, it follows that

$$-\frac{\partial e}{\partial x} = Ri. \tag{1}$$

The heat flux at the point x, $i(x,t)$ raises the temperature of a lamina of thickness dx at the rate of $\partial e/\partial t$. Therefore

$$-\frac{\partial i}{\partial x} = C\frac{\partial e}{\partial t}. \tag{2}$$

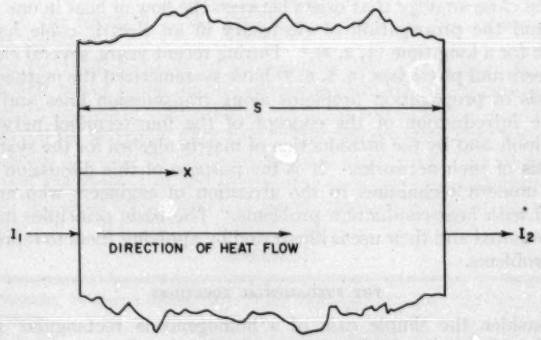

FIG. 1. Heat flow in a homogeneous slab.

If the heat flux, $i(x,t)$ is eliminated between Eqs. 1 and 2, the resulting equation is

$$\frac{\partial^2 e}{\partial x^2} = RC\frac{\partial e}{\partial t}. \tag{3}$$

The quantity

$$K = 1/RC = \frac{\text{(thermal conductivity)}}{\text{(density} \times \text{specific heat)}} \tag{4}$$

is the diffusivity, diffusion coefficient, or thermometric conductivity of the material of the slab.

Equations 1 and 2 are the equations that govern the propagation of current $i(x,t)$ and potential $e(x,t)$ in a uniform electric cable of capaci-

tance C and resistance R per unit length. This electrical analogy has been used to study heat-conduction problems by several investigators (1, 2, 3). The analogy makes it possible to use all the mathematical techniques of the theory of electric circuits in the study of linear heat-conduction problems. For example, the slab of Fig. 1 is completely analogous to the four-terminal network or quadripole of Fig. 2.

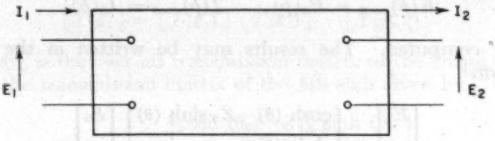

FIG. 2. Electric quadripole.

Let it be supposed that at $t = 0$, the slab of Fig. 1 is at a constant temperature. Let this constant temperature be taken as zero for simplicity. Now at $t = 0+$ a temperature $e_1(t)$ is impressed on the side $x = 0$ and another temperature $e_2(t)$ is impressed on the side $x = S$; $i_1(t)$ and $i_2(t)$ then represent the heat fluxes entering and leaving the slab. This thermal system is equivalent to the electrical system in which the circuit is inert at $t = 0$ and a potential $e_1(t)$ is impressed on the left terminals and $e_2(t)$ on the right terminals of the quadripole of Fig. 2.

In order to determine the heat fluxes $i_1(t)$ and $i_2(t)$, the simplest procedure is to introduce the following p-multiplied Laplace transforms (4)

$$L\,e(x,t) = p\int_0^\infty e^{-pt}e(x,t)dt = E(x,p) \tag{5}$$

$$L\,i(x,t) = p\int_0^\infty e^{-pt}i(x,t)dt = I(x,p). \tag{6}$$

If it is assumed that the initial temperature $e(x,0)$ and the initial heat flux $i(x,0)$ are both zero at $t = 0$, the transforms of Eqs. 1 and 2 are

$$-\frac{dE}{dx} = RI \tag{7}$$

and

$$-\frac{dI}{dx} = CpE. \tag{8}$$

The transform of Eq. 3 is

$$\frac{d^2E}{dx^2} = RCpE. \tag{9}$$

Let the p-multiplied Laplace transforms of the various quantities involved be represented by capital letters so that $L\, e_k(t) = E_k(p)$ and $L\, i_k(t) = I_k(p)$.

The solutions of the differential Eqs. 7 and 8 subject to the following boundary conditions:

$$\left.\begin{aligned} E(p)_{x=0} &= E_1(p), & I(p)_{x=0} &= I_1(p) \\ E(p)_{x=s} &= E_2(p) & I(p)_{x=s} &= I_2(p) \end{aligned}\right\} \tag{10}$$

are easily computed. The results may be written in the following matrix form:

$$\begin{bmatrix} E_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} \cosh(\theta) & Z_0 \sinh(\theta) \\ \dfrac{\sinh(\theta)}{Z_0} & \cosh(\theta) \end{bmatrix} \cdot \begin{bmatrix} E_2 \\ I_2 \end{bmatrix} \tag{11}$$

where

$$\theta = Sa \tag{12}$$

$$a = \sqrt{RCp} = \text{operational propagation constant} \tag{13}$$

$$Z_0 = \sqrt{\frac{R}{Cp}} = \text{operational characteristic impedance.} \tag{14}$$

The quantity a is the operational propagation constant, and Z_0 is the operational characteristic impedance of the quadripole of Fig. 2.

The square matrix

$$[T(\theta)] = \begin{bmatrix} \cosh(\theta) & Z_0 \sinh(\theta) \\ \dfrac{\sinh(\theta)}{Z_0} & \cosh(\theta) \end{bmatrix} = \begin{bmatrix} A & B \\ C & A \end{bmatrix} \tag{15}$$

is the operational transmission matrix of the quadripole of Fig. 2. The operational transmission matrix is very useful in the solution of linear heat-flow problems. If the specific heat of the slab of Fig. 1 is *negligible* so that the slab possesses only a *total* thermal resistance of R_T, the operational transmission matrix (15) reduces to

$$[T(\theta)]_{C=0} = \begin{bmatrix} 1 & R_T \\ 0 & 1 \end{bmatrix} \text{(negligible } C\text{)}. \tag{16}$$

COMPOSITE SLABS

Slabs in Series

The transmission matrix is particularly well-adapted for the study of heat-conduction problems in composite solids. For example, consider

a composite wall composed of n slabs of thicknesses $S_1, S_2, \cdots S_n$, thermal resistances per unit length of $R_1, \cdots R_n$, and heat capacitances $C_1 \cdots C_n$. It is evident that since the temperatures at the interfaces of adjacent slabs are equal and the heat flux that emerges from one slab enters the adjacent slab, therefore the over-all operational transmission matrix of the entire wall is given by the products of the individual transmission matrices of the separate slabs in the form

$$[T(\theta)] = [T(\theta_1)]\,[T(\theta_2)] \cdots [T(\theta_n)] \tag{17}$$

where $[T(\theta)]$ is the over-all transmission matrix of the entire wall, and $[T(\theta_k)]$ is the transmission matrix of the kth slab given by

$$[T(\theta_k)] = \begin{bmatrix} \cosh(\theta_k) & Z_{0K} \sinh(\theta_k) \\ \dfrac{\sinh(\theta_k)}{Z_{0K}} & \cosh(\theta_k) \end{bmatrix} \tag{18}$$

and

$$\theta_k = S_k \sqrt{R_k C_k p}, \qquad Z_{0K} = \sqrt{R_k / C_k p}. \tag{19}$$

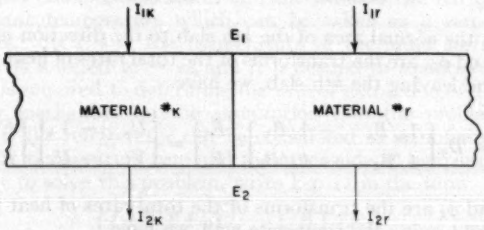

FIG. 3. Slabs in parallel.

The over-all transmission matrix is thus seen to be obtained by a process of matrix multiplication. It enables one to write the relations between the temperatures and heat fluxes on both sides of the composite wall in a most direct manner. The process of matrix multiplication replaces the laborious evaluation of arbitrary constants at the various interfaces as is done when the classical method is employed to solve this type of problem (**8**).

Slabs in Parallel

Consider the composite wall of Fig. 3. This wall consists of n-slabs of different materials in parallel. Matrix algebra facilitates the solution of problems involving composite walls of this type provided a certain simplifying approximation can be made.

Let the transforms of the temperature on the two sides of the wall be E_1 and E_2. Let I_{1k} be the transform of the heat flux entering the kth slab and I_{2k} be the transform of the heat flux emerging from the kth slab. If it can be assumed that the heat flux across boundaries between any two slabs of different materials can be *neglected* in comparison with the heat fluxes in these slabs that flows normal to the wall, the following relations will exist for each slab

$$\begin{bmatrix} E_1 \\ I_{1k} \end{bmatrix} = \begin{bmatrix} \cosh(\theta_k) & Z_{0K} \sinh(\theta_k) \\ \dfrac{\sinh(\theta_k)}{Z_{0K}} & \cosh(\theta_k) \end{bmatrix} \cdot \begin{bmatrix} E_2 \\ I_{2k} \end{bmatrix} \tag{20}$$

$$= \begin{bmatrix} A_k & B_k \\ C_k & D_k \end{bmatrix} \begin{bmatrix} E_2 \\ I_{2k} \end{bmatrix}.$$

The above relation may also be written in the following form:

$$\begin{bmatrix} I_{1k} \\ I_{2k} \end{bmatrix} \begin{bmatrix} A_k/B_k & -1/B_k \\ 1/B_k & -A_k/B_k \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \end{bmatrix}. \tag{21}$$

If D_k is the normal area of the kth slab to the direction of heat flow and if ϕ_{1k} and ϕ_{2k} are the transforms of the total rates of heat per second entering and leaving the kth slab, we have

$$\begin{bmatrix} \phi_{1k} \\ \phi_{2k} \end{bmatrix} = D_k \begin{bmatrix} A_k/B_k & -1/B_k \\ 1/B_k & -A_k/B_k \end{bmatrix} \cdot \begin{bmatrix} E_1 \\ E_1 \end{bmatrix} = \begin{bmatrix} U_k & -V_k \\ V_k & -U_k \end{bmatrix} \cdot \begin{bmatrix} E_1 \\ E_2 \end{bmatrix}. \tag{22}$$

If ϕ_1 and ϕ_2 are the transforms of the total rates of heat per second entering and leaving the composite wall, we have

$$\begin{bmatrix} \phi_1 \\ \phi_2 \end{bmatrix} = \sum_{k=1}^{n} \begin{bmatrix} \phi_{1k} \\ \phi_{2k} \end{bmatrix} = \sum_{k=1}^{n} \begin{bmatrix} U_k & -V_k \\ V_k & -U_k \end{bmatrix} \cdot \begin{bmatrix} E_1 \\ E_2 \end{bmatrix}. \tag{23}$$

If the underlying approximations under which Eq. 23 is valid can be made, it may be used to advantage in studying the heat flow in buildings when they are undergoing periodic temperature variations. The periodic heating may be assumed to be produced by periodic internal heating or by a periodically varying external temperature. The transmission matrices of the various parts of the building such as walls, doors, windows, air spaces, etc., may be obtained and the over-all matrix

$$[W] = \sum_{k=1}^{n} \begin{bmatrix} U_k & -V_k \\ V_k & -U_k \end{bmatrix} \tag{24}$$

calculated. The transforms of the rates of heat entering and leaving the entire structure are then given by

$$\begin{bmatrix} \phi_1 \\ \phi_2 \end{bmatrix} = [W] \begin{bmatrix} E_1 \\ E_2 \end{bmatrix}. \tag{25}$$

TRANSIENT HEAT-CONDUCTION PROBLEMS

When the operational transmission matrix (15) is known, problems involving transient heat conduction may be solved by the use of the Laplace transformation (9) with an economy of algebraic effort. The computation of the inverse transforms involved may present formidable difficulties, but the matrix formulation of the problem reduces the algebraic labor involved to a minimum. As a simple example of the use of the transmission matrix in heat-conduction problems, consider the following problems.

Heat Extraction from a Refrigerator

A household refrigerator consists of a rectangular box, the walls being made of thermal insulating material of thickness S. Originally the inner and outer temperatures and the walls of the refrigerator are at a constant temperature which can be taken as a zero reference temperature. At $t = 0$, the temperature of the inner surface of the refrigerator is lowered to $-e_0$, and it is desired to maintain it at this value. It is required to determine the rate of extraction of heat by the refrigerator mechanism on the assumption that the problem can be treated as if the refrigerator can be considered as an infinite slab one side being at temperature zero and the other side at temperature $-e_0$.

In order to solve this problem, write Eq. 11 in the form

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} A/B & -1/B \\ 1/B & -A/B \end{bmatrix} \cdot \begin{bmatrix} E_1 \\ E_2 \end{bmatrix} \tag{26}$$

where

$$A = \cosh(\theta), \qquad B = Z_0 \sinh(\theta). \tag{27}$$

Since the wall $x = 0$ is at zero temperature, $E_1 = 0$, and since $e_2 = -e_0$, $E_2 = -e_0$. If these values of E_1 and E_2 are inserted in Eq. 26 the result is

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} A/B & -1/B \\ 1/B & -A/B \end{bmatrix} \cdot \begin{bmatrix} 0 \\ -e_0 \end{bmatrix}. \tag{28}$$

Therefore by matrix multiplication the following results are obtained:

$$I_1 = e_0/B = e_0/Z_0 \sinh(\theta) \tag{29}$$

$$I_2 = e_0 A/B = e_0 \cosh(\theta)/Z_0 \sinh(\theta). \tag{30}$$

The inverse transforms of Eqs. 29 and 30 give the heat fluxes passing the interior and exterior walls of the refrigerator. The heat flux entering the refrigerator through its inner wall is given by

$$i_2 = L^{-1}I_2(p) = L^{-1}\frac{e_0 \cosh\,(S\sqrt{RCp})}{\sqrt{\frac{R}{Cp}}\cdot\sinh\,(S\sqrt{RCp})}. \tag{31}$$

This inverse transform may be calculated by the theory of residues in the usual manner (4). The result is

$$i_2 = \frac{e_0}{RS}[1 + 2\sum_{n=1}^{\infty} e^{-n^2\pi^2 t/S^2CR}]. \tag{32}$$

This is the rate of extraction of heat per unit area at the inner surface of the refrigerator. The series (32) is uniformly convergent for $t > 0$.

Temperature Distribution of an Insulated Slab

In order to give another illustration of the use of the operational transmission matrix, consider a slab of conducting material that is perfectly insulated at the face $x = S$ so that no heat can flow through this face. Let it be assumed that initially the entire slab is at zero temperature and that at $t = 0$ the face $x = 0$ is suddenly elevated to a temperature e_0. Let it be required to determine the subsequent temperature of the face $x = S$.

In this case, Eq. 11 reduces to

$$\begin{bmatrix} e_0 \\ I_1 \end{bmatrix} = \begin{bmatrix} \cosh\,(\theta) & Z_0 \sinh\,(\theta) \\ \dfrac{\sinh\,(\theta)}{Z_0} & \cosh\,(\theta) \end{bmatrix} \cdot \begin{bmatrix} E_2 \\ 0 \end{bmatrix}. \tag{33}$$

By matrix multiplication, we obtain

$$e_0 = E_2 \cosh\,(\theta), \qquad I_1 = E_2 \sinh\,(\theta)/Z_0. \tag{34}$$

These equations may be solved for E_2 and I_1 and the results are

$$E_2 = e_0/\cosh\,(\theta) \tag{35}$$

and

$$I_1 = e_0 \tanh\,(\theta)/Z_0. \tag{36}$$

In order to determine the temperature of the face $x = S$, it is necessary to compute the inverse transform of E_2. To do this, E_2 may be written in the following form

$$E_2 = 2E_0/(e^{\theta} + e^{-\theta}) = 2E_0(e^{-\theta} - e^{-3\theta} + e^{-5\theta} - e^{-7\theta} + \cdots). \quad (37)$$

Let

$$a = S\sqrt{RC}, \qquad \theta = a\sqrt{p}. \quad (38)$$

With this notation, Eq. 37 may be written in the following form

$$E_2 = 2e_0(e^{-a\sqrt{p}} - e^{-3a\sqrt{p}} + e^{-5a\sqrt{p}} - e^{-7a\sqrt{p}} + \cdots). \quad (39)$$

The series (39) is uniformly convergent because $Rep > 0$ as is shown in works on the Laplace transform theory (9).

The following result may be obtained from a table of Laplace transforms (4)

$$L^{-1}e^{-k\sqrt{p}} = erfc(k/2\sqrt{t}), \qquad k > 0 \quad (40)$$

where the function $erfc(x)$ is the complementary error function defined by the expression

$$erfc(x) = 1 - \frac{2}{\sqrt{\pi}}\int_0^x e^{-u^2}\,du. \quad (41)$$

This function is well known and extensive tables of it exist (9). The inverse transform of (39) is, therefore,

$$e_2 = 2e_0[erfc(a/2\sqrt{t}) - erfc(3a/2\sqrt{t}) + erfc(5a/2\sqrt{t}) - erfc(7a/2\sqrt{t}) + \cdots]. \quad (42)$$

This is the temperature of the insulated face of the slab. The heat flux entering the slab may be obtained by computing the inverse transform of I_1 as given by Eq. 36 in a similar manner.

PROBLEMS INVOLVING OSCILLATORY TEMPERATURE VARIATIONS

Problems involving temperature variations which are periodic functions of the time are of great practical importance in the study of the fluctuations of the temperature of the earth's crust due to the periodic heating of the sun, in various experimental arrangements for the determination of the diffusivity, in the calculation of the periodic temperature variation of the cylinder walls of steam and internal-combustion engines and in the theory of automatic temperature-control systems.

The operational transmission matrix can be adapted to facilitate the solution of heat-conduction problems involving harmonic temperature variations. In problems of this type the temperature and heat flux oscillate with respect to time and contain a factor of sin $(wt + \phi)$

where ϕ is a phase angle and $w = 2\pi \times$ the frequency of the temperature oscillation. To solve problems of this type it is necessary to modify the operational propagation constant a and the operational characteristic impedance Z_0 as given by Eqs. 13 and 14 to introduce the complex propagation constant $\bar{a}$ and the complex characteristic impedance $\bar{Z}_0$ defined by the equations

$$\bar{a} = (a)_{p=jw} = \sqrt{jwRC}, \qquad j = \sqrt{-1} \tag{43}$$

and

$$\bar{Z}_0 = (Z_0)_{p=jw} = \sqrt{R/jwc}. \tag{44}$$

If we let

$$\bar{\theta} = s\bar{a} = s\sqrt{jwRC} \tag{45}$$

then, instead of Eq. 11 we may write

$$\begin{bmatrix} \bar{E}_1 \\ \bar{I}_1 \end{bmatrix} = \begin{bmatrix} \cosh(\bar{\theta}) & \bar{Z}_0 \sinh(\bar{\theta}) \\ \dfrac{\sinh(\bar{\theta})}{\bar{Z}_0} & \cosh(\bar{\theta}) \end{bmatrix} \cdot \begin{bmatrix} \bar{E}_2 \\ \bar{I}_2 \end{bmatrix}. \tag{46}$$

In Eq. 46, $\bar{E}_1$ and $\bar{E}_2$ are the complex temperatures and $\bar{I}_1$ and $\bar{I}_2$ are the complex heat fluxes. These quantities correspond exactly to the complex potentials and currents of an electric cable in the steady-state periodic alternating-current case. The square matrix of Eq. 46 in the complex transmission matrix of the slab.

To illustrate the use of the complex transmission matrix in the solution of a period heat-conduction problem, consider the following representative problem:

Let the temperature variation of the face $x = 0$ of the slab of Fig. 1 be maintained at a temperature of $e_1 = E_m \sin(wt)$ and let the temperature of the face $x = S$ be maintained at zero. When a steady periodic state has been reached, let it be required to determine the heat flux that passes through the face $x = S$.

In order to solve this problem, we follow the usual procedure of alternating current theory (10) and write

$$e_1(t) = E_m \sin(wt) = \text{Im}\left[E_m e^{jwt}\right] \tag{47}$$

where the symbol "Im" means "the imaginary part of." Equation 46 in this case reduces to

$$\begin{bmatrix} E_m \\ \bar{I}_1 \end{bmatrix} = \begin{bmatrix} \cosh(\bar{\theta}) & \bar{Z}_0 \sinh(\bar{\theta}) \\ \dfrac{\sinh(\bar{\theta})}{\bar{Z}_0} & \cosh(\theta) \end{bmatrix} \cdot \begin{bmatrix} 0 \\ \bar{I}_2 \end{bmatrix}. \tag{48}$$

In Eq. 48 E_m is used as a reference temperature and all the phases are determined with respect to the temperature $e_1 = E_m \sin(wt)$.

By matrix multiplication the following equations are obtained

$$E_m = \bar{Z}_0 \sinh(\theta) \bar{I}_2 \tag{49}$$

and

$$\bar{I}_1 = \bar{I}_2 \cosh(\theta). \tag{50}$$

Hence

$$\bar{I}_2 = E_m / \bar{Z}_0 \sinh(\theta) \tag{51}$$

$$I_1 = E_m / \bar{Z}_0 \tanh(\theta). \tag{52}$$

The instantaneous heat flux that passes through the wall $x = S$ is given by

$$i_2 = \text{Im}\,[\bar{I}_2 e^{iwt}]. \tag{53}$$

Since $\bar{Z}_0$ and $\sinh(\theta)$ are complex numbers, they may be written in the following polar form

$$\bar{Z}_0 = |Z_0| e^{i\phi_1}, \qquad \sinh(\theta) = |\sinh(\theta)| e^{i\phi_2}. \tag{54}$$

Hence

$$\left.\begin{aligned} i_2 &= \text{Im}\,[E_m e^{i(wt-\phi_1-\phi_2)} / |\bar{Z}_0| \cdot |\sinh(\theta)|] \\ &= E_m \sin(wt - \phi_1 - \phi_2) / |Z_0| \cdot |\sinh(\theta)| \end{aligned}\right\}. \tag{55}$$

This expression gives the amplitude and phase of the heat flux entering the wall $x = S$ with respect to the temperature variation $E_m \sin(wt)$ of the wall $x = 0$. The flux is thus seen to have a phase lag of $(\phi_1 + \phi_2)$. It can be seen from Eq. 53 that the *modulus* of $\bar{I}_2$ gives the amplitude of the heat flux and the *argument* of $\bar{I}_2$ determines the phase of the heat flux.

By the use of complex transmission matrices, problems involving periodic heat conduction in composite slabs may be solved readily by the theory given in the third section of the paper. The solution of problems of this type involves manipulation of complex numbers and the matrix notation greatly facilitates the algebraic manipulations involved.

REFERENCES

(1) OLIVER HEAVISIDE, "Electromagnetic Theory," Vol. 2, New York, Dover Publications, 1949, pp. 127–128.

(2) E. J. BERH, "Heaviside's Operational Calculus," New York, McGraw-Hill Book Co., Inc., 1936, pp. 134–139.

(3) R. C. L. BOSWORTH, "Heat Transfer Phenomena," New York, John Wiley & Sons, Inc., 1952, Chapter 8.
(4) L. A. PIPES, "Applied Mathematics for Engineers and Physicists," New York, McGraw-Hill Book Co., Inc., 1946, Chapter 18.
(5) L. A. PIPES, "The Transient Behaviour of Four-Terminal Networks," *Phil. Mag.*, Ser. 7, Vol. 33, 1942, pp. 174–214.
(6) L. A. PIPES, "The Matrix Theory of Four-Terminal Networks," *Phil. Mag.*, Ser. 7, Vol. 30, 1940, pp. 370–395.
(7) LEON BRILLOUIN, "Wave Propagation in Periodic Structures," New York, Dover Publications, 1953.
(8) W. A. MERSMAN, W. P. BERGGREN, AND L. M. K. BOELTER, "The Conduction of Heat in Composite Infinite Solids," Berkeley, University of California Press, 1942.
(9) H. S. CARSLAW AND J. C. JAEGER, "Conduction of Heat in Solids," London, Oxford University Press, 1947, Chapter 11.
(10) E. A. GUILLEMIN, "Communication Networks," Vol. 2, New York, John Wiley & Sons, Inc., 1935.

SIMPLE BRIDGE METHOD FOR THE MEASUREMENT OF THERMAL CONDUCTIVITY OF GASES AND GAS MIXTURES *

BY

MAHENDRA P. MADAN [1]

ABSTRACT

A simple bridge method for the measurement of thermal conductivity of gases or gaseous mixtures is discussed and its design developed. A rigorous mathematical theory is applied to calculate the various corrections and to obtain the value of the thermal conductivity in terms of the conveniently measured quantities.

1. INTRODUCTION

The phenomena of heat conduction and energy transfer form one of the transport properties for which theory alone is inadequate; therefore experimental determination is of great importance to theoretical as well as applied physics, particularly when dealing with problems of heat transfer.

Nearly all methods for the measurement of thermal conductivity employ some form of electrically heated metal wire, mounted axially in a glass or metal tube. The wire remains at a uniform temperature along a central portion, which will be relatively greater in extent, the longer the wire and the smaller its diameter. The lateral heat transfer through the gas is radial only for a limited central portion of the tube and the principal difficulty one encounters is to account for the heat conducted longitudinally by the wire. Usually three different procedures are used to correct for it:

i. A long thin wire to which two very fine potential leads are attached is used to measure the resistance of the central portion of the wire which is at a uniform temperature (1, 2).[2]

ii. Two tubes are employed, one long and the other short, usually called compensating cells. Differential measurements then refer to the central portion of the longer tube, where radial flow conditions hold (3, 4).

In these two procedures the end conduction is greatly reduced or may cancel out; but other factors, such as a lead wire correction introduced in the first method that cannot be calculated accurately

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

and the constructional inconvenience involved in the second method, are a great drawback.

iii. In the thick wire cell method end effect is large but it is almost exactly corrected by a rigorous application of the theory with the help of relatively simple boundary conditions (5, 6). This method can be modified by taking thin wire to minimize the radiation as well as the end loss.

Many workers employ heat conduction, using a balance bridge for gas analysis and also for measurement of low pressures. Some have even used it for the study of thermal diffusion of gaseous isotopes and gaseous mixtures (7). Such a thermal-conductivity gauge is a useful, simple, and inexpensive instrument. An attempt has been made in the following sections to discuss its use in obtaining accurate values of the thermal conductivity of any gas or gas mixture. For this purpose, a method based on the theory of Kannuluik and Martin (5) has been developed for the case of a thin wire and applied to an improved form of the balance bridge described by Grew (7). Several other corrections associated with the measurement of thermal conductivity are also discussed.

LIST OF SYMBOLS

K_u = thermal conductivity of the gas
K_g = thermal conductivity of glass tube
K_a = apparent conductivity of the gas in the presence of temperature jump
K_1; K_2 = gas conductivities at the temperature of the wire and the tube surface
λ = thermal conductivity of wire
r_1 = radius of the wire
r_2 = internal radius of the tube
r_3 = external radius of the tube
R = resistance of the wire
ρ_0 = resistance per unit length of wire at 0° C.
α = mean temperature coefficient of wire between 0° C. and θ°
$2l$ = length of wire
θ_1 = excess temperature of wire over that of the bath
θ_u = difference in temperature between inner and outer walls of the tube
g_1; g_2 = constants depending on the accommodation coefficient at the surface of the wire and the tube
δ = displacement of the wire from the axis of the tube
C = conductivity-cell constant

2. THEORY

The general theory of the distribution of temperature along the axially mounted wire as applied to our case may be briefly stated as follows.

Let us assume that the ends of the wire are held at the same steady temperature as the walls of the tube and that this temperature is taken as arbitrary zero. If we neglect convection and radiation, for the present, the differential equation for the steady flow of heat is

$$\pi r_1^2 \lambda \frac{d^2\theta}{dz^2} + 2\pi r_1 K_u \left(\frac{d\theta}{dr}\right)_{r=r_1} + \frac{I^2\rho_0(1+\alpha\theta)}{J} = 0 \qquad (1)$$

where λ and K_u are the thermal conductivities of the wire and the gas in cal/cm-sec-deg, respectively. ρ_0 is the resistance per unit length of the wire at 0° C., α is the mean temperature coefficient of resistance of the wire between 0° C. and θ°; and r_1 is the radius of the wire. The radial flow of heat is

$$2\pi r_1 K_u \left(\frac{d\theta}{dr}\right)_{r=r_1} = -\frac{2\pi K_u \theta}{\log_e r_2/r_1} = -2\pi r_1 h\theta \text{ (say)} \qquad (2)$$

where r_2 is the internal radius of the tube. Equation 1 then becomes

$$\pi r_1^2 \lambda \frac{d^2\theta}{dz^2} - 2\pi r_1 h\theta + I^2\rho_0(1+\alpha\theta)/J = 0. \qquad (3)$$

For the case in which the cell is highly evacuated, the second term in Eq. 3 represents the loss by radiation from the wire, denoting the loss of heat per unit area per unit difference of temperature.

Writing Eq. 3 in the form

$$d^2\theta/dz^2 = P^2\theta - Q$$

where

$$\left.\begin{aligned} P^2 &= 2h/r_1\lambda - I^2\rho_0\alpha/\pi r_1^2\lambda J \\ Q &= I^2\rho_0/\pi r_1^2\lambda J \end{aligned}\right\} \qquad (4)$$

and assuming P to be positive, we get the solution

$$\theta = Q/P^2 + A \sinh z + B \cosh z. \qquad (5)$$

The constants A and B are determined from the boundary conditions $\theta = 0$ at $x = \pm l$, $2l$ being the length of the wire. Equation 5 then yields

$$\theta = \frac{Q}{P^2}\left[1 - \frac{\cosh Pz}{\cosh Pl}\right]. \qquad (6)$$

The resistance R of the wire under present conditions of heating is given by

$$R = \int_{-l}^{+l} (1+\alpha\theta)dz. \qquad (7)$$

Substituting the value of θ from (6) and integrating for z from $-l$ to $+l$, we obtain

$$\frac{R - R_0}{R_0} = \frac{Q\alpha}{P}\left[1 - \frac{\tanh Pl}{Pl}\right] \qquad (8)$$

where $R_0 = 2\rho_0 l$. This equation can be written in the form

$$\left(\frac{1}{Pl}\right)^2\left(1 - \frac{\tanh Pl}{Pl}\right) = \frac{2\pi r_1^2 \lambda J(R - R_0)}{R_0^2 I^2 \alpha l}. \qquad (9)$$

If we substitute the experimentally determined values of R, R_0, α, and λ, then the value of the left-hand side of Eq. 9 is known; hence the conductivity K_w of the gas found from Eqs. 4 and 2 is also obtained.

To determine λ the experiment is performed in a perfect vacuum. The solution is again given by (9). Calculations shows that with the small current and thin wire P^2 is positive; therefore Eq. 9 cannot be further simplified. Hence Eq. 9 should be used to determine λ.

Equation 9 has been obtained on the assumption that the flow of heat through the gas is strictly radial. Actually, the lines of heat flow show some curvature at the ends of the tube. Under these conditions, the exact solution of Eq. 1 shows (5) that the error due to this correction is less than one per cent. Convection can be eliminated by working at sufficiently low pressures at which the observed conductivity becomes independent of the pressure.

3. METHOD AND CORRECTIONS

The apparatus for the measurement of the conductivity consists essentially of (i) the conductivity cell, (ii) the electrical bridge, (iii) the thermostatic bath (based on an analyser used in thermal diffusion measurements).

The conductivity cell can be made of metal, preferably of stainless steel, but the simplest way of designing it is to weld a very thin metallic wire to short platinum wires that are then sealed in a uniform capillary tubing. The capillary can be connected by a side tube to a manometer to measure the pressure. The assembly is suitably mounted on a wooden stand and immersed in a thermostat containing paraffin oil or any suitable fluid. The cell wire forms one arm of a Wheatstone bridge and a thicker wire (compensating resistance) made of the same material forms the second arm; the remaining two arms consist of two equal Eureka resistances, all being immersed in the bath. The temperature, and therefore resistance of the cell wire, depends on the conductivity of the gas surrounding it and on the current flowing through it. Its resistance is measured at the bath temperature and the compensating resistance is so adjusted that when the bridge is balanced, the cell wire is about 20° C. above the bath temperature. As the compensating resistance is made of the same material as the cell wire, but is many times thicker, its resistance is practically independent of the bridge current and the fluctuations in the temperature of the bath do not affect the bridge balance. To further ensure this balance the compensating coil can be mounted as near the cell as possible.

In operation, the conductivity apparatus is completely evacuated and a small amount of the desired gas or gas mixture of known composition is introduced, and is then compressed to the desired pressure. The current is adjusted approximately to balance the bridge and sufficient time is allowed for the temperature of the cell wire and the surrounding bath to attain a steady state. The current is then exactly adjusted for the balance and is measured across a standard resistance. For this balance the resistance of the cell will be equal to the resistance of the compensating coil at the temperature of the bath, which can be found from a previous calibration. The geometrical constants of the cell are determined before assembly. Then the tube is highly evacuated and very small heating currents are passed through it to measure the resistance by the potentiometer method, and then extrapolated to zero current. These observations are also utilized to determine λ. This value of λ along with the values of R, R_0 and α is substituted in Eq. 9 to give P from which h and K_u are calculated with the help of Eq. 4.

This value of K_u must be further corrected for the temperature gradient across the wall, for the accommodation coefficient (or the temperature jump effect) at the surfaces of the wire and the tube, and for the curvature of the lines of heat flow near the ends.

The wall effect is corrected for by treating the present case as a conduction through composite cylinders of gas and glass. We have for the heat transmission

$$\frac{2\pi K_u'(\theta - \theta_\omega)}{\log_e r_2/r_1} = \frac{2\pi K_g \theta_\omega}{\log_e r_3/r_2} \tag{10}$$

where θ_1 is the excess temperature of the wire over that of the bath, θ_ω is the difference in temperature between inner and outer walls of the tube, r_3 is the external radius of the tube, and K_g is the conductivity of the glass tube. Therefore,

$$\theta_\omega = (K_u'/K_g)[(\log_e r_3/r_2)/(\log_e r_2/r_1)](\theta_1 - \theta_\omega) \tag{11}$$

and in the place of the second term in Eq. 1 we have:

$$\frac{2\pi K_u'}{\log_e r_2/r_1}(\theta - \theta_\omega) = \frac{2\pi K_u'}{\log_e r_2/r_1}\theta\left(1 - \frac{K_u' \log_e r_3/r_2}{K_g \log_e r_2/r_1}\right). \tag{12}$$

Hence on taking the wall correction, h in Eq. 3 must be replaced by h' where

$$h' = \frac{K_u'}{r_1 \log_e r_2/r_1}\left(1 - \frac{K_u' \log_e r_3/r_2}{K_g \log_e r_2/r_1}\right). \tag{13}$$

Thus, if K_g is known, K_u (corrected for wall effect) can be determined.

The correction for the temperature jump at the wire and the tube surfaces has been fully discussed by Gregory and Archer (3) and by Taylor and Johnston (2). They have shown that

$$\frac{1}{K_a} = \frac{1}{K} + \frac{1}{p \log_e r_2/r_1}\left[\frac{g_1}{K_1 r_1} + \frac{g_2}{K_2 r_2}\right] \tag{14}$$

where K_a is the apparent conductivity, K is the conductivity corrected for temperature jump effect, K_1, K_2 are the gas conductivities at the temperature of the wire and the tube surface, and g_1, g_2 depend upon the accommodation coefficient at the surface of the wire and the tube. Thus by plotting $1/K_a$ against $1/p$, the true conductivity can be determined from the intercept.

Kannuluik and Martin (5) have discussed the effect of the slight displacement δ of the wire from the axis of the tube and have shown that

$$K = K_u\left[1 - \frac{\delta^2/(r_2^2 - r_1^2)}{\log_e r_2/r_1}\right] = K_u(1 - C) \tag{15}$$

where K_u is the uncorrected conductivity and C is independent of the gas. By working with a gas of known conductivity, the constant C for the cell is determined once and for all, and the apparatus can then be used for finding the conductivity of any gas or gaseous mixture.

The method has been successfully applied to obtain reliable and accurate values of the conductivity by the author and, with further modifications, by Srivastava and his group (8).

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REFERENCES

(1) S. WEBER, *Ann. Physik*, Vol. 54, p. 325 (1917).
(2) W. J. TAYLOR AND H. L. JOHNSTON, *J. Chem. Phys.*, Vol. 14, p. 219 (1946).
(3) H. S. GREGORY AND C. T. ARCHER, *Proc. Roy Soc.* (London) Series A, Vol. 110, p. 91 (1926).
(4) B. G. DICKINS, *Ibid.*, Vol. 143, p. 517 (1934).
(5) W. G. KANNULUIK AND L. H. MARTIN, *Ibid.*, Vol. 141, p. 144 (1933); Vol. 144, p. 496 (1934).
(6) W. G. KANNULUIK AND E. H. CARMEN, *Proc. Phys. Soc.* (London) Series A, Vol. 65, p. 701 (1952).
(7) K. E. GREW, *Proc. Roy Soc.* (London) Series A, Vol. 178, p. 390 (1941); T. L. IBBS, K. E. GREW AND A. A. HIRST, *Proc. Phys. Soc.* (London), Vol. 41, p. 456 (1929).
(8) B. N. SRIVASTAVA, Indian Association for the Cultivation of Sciences, Calcutta, Private Communication; B. N. SRIVASTAVA AND M. P. MADAN, *Proc. Nat. Inst. Sci.*, Vol. 20, p. 587 (1954).

THE CLASSICAL ELECTROMAGNETIC EQUATIONS EXPRESSED AS COMPLEX FOUR-DIMENSIONAL QUANTITIES *

BY

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ABSTRACT

It is possible to compress the classical electromagnetic equations into three complex, four-dimensional quantities Ω', $^4\bar{\Gamma}'$, and $^4\bar{\Psi}'$. These quantities represent in order electromagnetic fields, currents and charges, and vector and scalar potentials. In addition to the four-dimensional quantities, a complex vector $\bar{Q}' = a\bar{E} + jb\bar{B}$ is introduced, where $\bar{E}$ = electric fieldstrength, $\bar{B}$ = magnetic induction, $j = \sqrt{-1}$, and a and b are real or pure imaginary constants. The components of $\bar{Q}'$ represent two related modes, one electric and one magnetic.

INTRODUCTION

In many electromagnetic wave problems in which symmetry exists between the electric and magnetic modes, for instance in problems dealing with waveguides, cavities and antennas in the microwave field, it is convenient to introduce a complex vector $\bar{Q}' = a\bar{E} + jb\bar{B}$, where $\bar{E}$ = electric field strength, $\bar{B}$ = magnetic induction, $j = \sqrt{-1}$, and a and b are real or pure imaginary constants. (A bar over a letter indicates a vector, an apostrophe a complex quantity.) Thus the components of the complex vector $\bar{Q}'$ represent two related modes, one electric, and one magnetic. The vector can be used throughout the problem and then finally split into its two parts. Thus the calculations will be simplified and easily examined.

This idea is not new. In 1901 Weber (1)[2] used a quantity $\mathcal{E} + i\mathfrak{M}(a = 1,\ b = 1/\mu,\ j = i)$ for the purpose of compressing Maxwell's equations. Silberstein in three papers (2, 3, 4) introduced different notations: $E_1 + iE_2\ (a = 1,\ b = 1/\mu)$; $\sqrt{\epsilon}E_1 + i\sqrt{\mu}E_2\ (a = \sqrt{\epsilon},\ b = 1/\sqrt{\mu})$; and $\bar{M} - i\bar{E}\ (a = -i,\ b = -i/\mu)$. Bateman (5) used $H \pm iE\ (a = \pm i,\ b = -i/\mu)$. In all these cases $\mathcal{E}$, E_1, $\bar{E}$, and E represent the electric mode; and $\mathfrak{M}$, E_2, $\bar{M}$, and H, the magnetic mode. The dielectric constant is ϵ and μ is the permeability. Finally, Stratton (6) gives $\bar{B} + i\sqrt{\epsilon\mu}\bar{E}\ (a = i\sqrt{\epsilon\mu},\ b = -i)$. Due consideration has to be given to the fact that different writers have used different units in defining electric and magnetic quantities.

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

However, there is another formal way of compressing the classical electromagnetic equations. This representation stems from the theory of relativity and utilizes four-dimensional quantities. (See 4, 6–11.)

In this paper an attempt will be made to show how two methods, the complex vector method and the four-vector method, can be combined so that the classical electromagnetic equations can be expressed by means of only three complex, four-dimensional quantities that represent the electromagnetic fields, the currents and charges, and the vector and scalar potentials.

I. COMPLEX VECTORS

1. *Definition of the Complex Field Vector*

As complete freedom exists in the choice of the components of the complex field vector, we shall use the dimensionally uniform notation

$$\bar{Q}' = \bar{E} + j\frac{1}{\sqrt{\epsilon\mu}}\bar{B} \tag{1}$$

(that is, $a = 1$, $b = 1/\sqrt{\epsilon\mu}$). This quantity has been chosen because high-frequency electrodynamic calculations are usually based upon the electric field vector. Letting $\bar{B} = \mu\bar{H}$, where $\bar{H}$ is the magnetic excitation, we also get

$$\bar{Q}' = \bar{E} + j\sqrt{\frac{\mu}{\epsilon}}\bar{H}. \tag{2}$$

After the complex field vector $\bar{Q}'$ has been chosen, all other complex electromagnetic quantities are completely determined. This will be shown in the following sections.

2. *Maxwell's Equations*

Maxwell's equations can be written in the following form (see, for example, 6, 11, 12):

$$\left.\begin{aligned} -\operatorname{curl}\bar{E} &= \frac{\partial\bar{B}}{\partial t} + \bar{J}_m \\ \operatorname{div}\bar{B} &= \rho_m \\ \bar{B} &= \mu\bar{H} \end{aligned}\right\} \qquad \left.\begin{aligned} \operatorname{curl}\bar{H} &= \frac{\partial\bar{D}}{\partial t} + \bar{J}_e \\ \operatorname{div}\bar{D} &= \rho_e \\ \bar{D} &= \epsilon\bar{E} \end{aligned}\right\} \tag{3}$$

where $\bar{D}$ is the electric displacement, $\bar{J}_e$ and $\bar{J}_m$ are the electric and (fictitious) magnetic current densities, and ρ_e and ρ_m are electric and (fictitious) magnetic charge densities.

Using $\bar{Q}'$ we get

$$\left.\begin{aligned} \text{curl } \bar{Q}' &= j\sqrt{\epsilon\mu}\,\frac{\partial \bar{Q}'}{\partial t} + j\sqrt{\frac{\mu}{\epsilon}}\,J' \\ \text{div } \bar{Q}' &= \frac{\rho'}{\epsilon} \end{aligned}\right\} \tag{4}$$

which are Maxwell's equations where

$$\left.\begin{aligned} J' &= J_e + j\sqrt{\frac{\epsilon}{\mu}}\,J_m \\ \rho' &= \rho_e + j\sqrt{\frac{\epsilon}{\mu}}\,\rho_m \end{aligned}\right\}. \tag{5}$$

J' indicates a new complex vector for the current density. As the charges ρ_e and ρ_m are scalars their complex combination, ρ', is a complex number.

With the new notation, the continuity equation is

$$\text{div } J' + \frac{\partial \rho'}{\partial t} = 0. \tag{6}$$

3. The Wave Equation

If, in the well-known vector formula, valid for rectangular coordinates,

$$\text{curl curl } \bar{C} = \nabla \text{ div } \bar{C} - \nabla^2 \bar{C}$$

we substitute the expressions for curl $\bar{Q}'$ and div $\bar{Q}'$ in Maxwell's equations, Eqs. 4, we obtain

$$\nabla^2 \bar{Q}' - \epsilon\mu\,\frac{\partial^2 \bar{Q}'}{\partial t^2} = \frac{\nabla \rho'}{\epsilon} + \mu\,\frac{\partial J'}{\partial t} - j\sqrt{\frac{\mu}{\epsilon}}\,\text{curl } J'. \tag{7}$$

This is the wave equation for $\bar{Q}'$. It can easily be split into the familiar wave equations

$$\left.\begin{aligned} \nabla^2 \bar{E} - \epsilon\mu\,\frac{\partial^2 \bar{E}}{\partial t^2} &= \frac{\nabla \rho_e}{\epsilon} + \mu\,\frac{\partial J_e}{\partial t} + \text{curl } J_m \\ \nabla^2 \bar{H} - \epsilon\mu\,\frac{\partial^2 \bar{H}}{\partial t^2} &= \frac{\nabla \rho_m}{\epsilon} + \epsilon\,\frac{\partial J_m}{\partial t} - \text{curl } J_e \end{aligned}\right\}. \tag{8}$$

4. Potentials

The electric fieldstrength $\bar{E}$ and the magnetic induction $\bar{B}$ are built up in the following way:

$$\left.\begin{aligned} \bar{E} &= \bar{E}_1 + \bar{E}_2 \\ \bar{E}_1 &= -\nabla\phi_e - \frac{\partial \bar{A}_m}{\partial t} \\ \bar{E}_2 &= -\frac{1}{\epsilon}\operatorname{curl} \bar{A}_e \end{aligned}\right| \qquad \left.\begin{aligned} \bar{B} &= \bar{B}_1 + \bar{B}_2 \\ \bar{B}_1 &= -\mu\nabla\phi_m - \mu\cdot\frac{\partial \bar{A}_e}{\partial t} \\ \bar{B}_2 &= \operatorname{curl} \bar{A}_m \end{aligned}\right| \tag{9}$$

where $\bar{A}_m$ and $\bar{A}_e$ are the electric and magnetic vector potentials, respectively, and ϕ_e and ϕ_m are the electric and magnetic scalar potentials. Using the definition of $\bar{Q}'$ given above we immediately obtain

$$\bar{Q}' = -\nabla\phi' - \frac{\partial \bar{A}'}{\partial t} + \frac{j}{\sqrt{\epsilon\mu}}\operatorname{curl} \bar{A}' \tag{10}$$

where

$$\left.\begin{aligned} \bar{A}' &= \bar{A}_m + j\sqrt{\frac{\mu}{\epsilon}}\,\bar{A}_e \\ \phi' &= \phi_e + j\sqrt{\frac{\mu}{\epsilon}}\,\phi_m \end{aligned}\right| . \tag{11}$$

The complex vector potential $\bar{A}'$ and the complex scalar potential ϕ', introduced herein, are connected with the complex current density J' and the complex charge ρ' by means of the well-known expressions

$$\left.\begin{aligned} \bar{A}' &= \frac{\mu}{4\pi}\int_V \frac{J' e^{-i\bar{k}\bar{r}}}{r}\,d\tau \\ \phi' &= \frac{1}{4\pi\epsilon}\int_V \frac{\rho' e^{-i\bar{k}\bar{r}}}{r}\,d\tau \end{aligned}\right| \tag{12}$$

where

$$\bar{k} = (k_x, k_y, k_z) \text{ and } \bar{r} = (x, y, z).$$

If we impose the following condition between $\bar{A}'$ and ϕ'

$$\operatorname{div} \bar{A}' + \epsilon\mu\cdot\frac{\partial \phi'}{\partial t} = 0, \tag{13}$$

we obtain by substituting Eq. 10 in Eq. 4

$$\left.\begin{aligned} \nabla^2 \bar{A}' - \epsilon\mu \cdot \frac{\partial^2 \bar{A}'}{\partial t^2} &= -\mu \bar{J}' \\ \nabla^2 \phi' - \epsilon\mu \cdot \frac{\partial^2 \phi}{\partial t^2} &= -\frac{\rho'}{\epsilon} \end{aligned}\right\}. \tag{14}$$

Sometimes it is convenient to introduce the Hertzian vector $\bar{\Pi}'$ by putting

$$\bar{A} = \epsilon\mu \cdot \frac{\partial \bar{\Pi}'}{\partial t}. \tag{15}$$

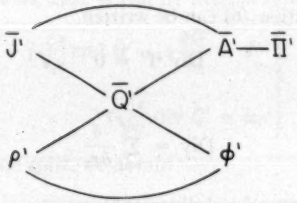


FIG. 1. Schematic diagram showing the connection between the complex quantities introduced.

5. Summary

Up to this point the following complex quantities have been introduced:

$$\left.\begin{aligned} \bar{Q}' &= \bar{E} + j\sqrt{\frac{\mu}{\epsilon}} \cdot \bar{H} \\ \bar{J}' &= \bar{J}_e + j\sqrt{\frac{\epsilon}{\mu}}\, \bar{J}_m \\ \rho' &= \rho_e + j\sqrt{\frac{\epsilon}{\mu}} \cdot \rho_m \\ \bar{A}' &= \bar{A}_m + j\sqrt{\frac{\mu}{\epsilon}}\, \bar{A}_e \\ \phi' &= \phi_e + j\sqrt{\frac{\mu}{\epsilon}} \cdot \phi_m \end{aligned}\right\}. \tag{16}$$

These quantities may be used to form the diagram of Fig. 1.

II. FOUR-DIMENSIONAL COMPLEX QUANTITIES

1. The Complex Four-Current Density

We now exchange the coordinates x, y, z, used above, for the following x_k world coordinates (see 6 and 11)

$$(x_1; x_2; x_3; x_4) = (x; y; z; ict) \tag{17}$$

where $c = 1/\sqrt{\mu\epsilon}$ is the velocity of light and i is the relativistic separating factor to be distinguished from the factor j used above.

If we introduce the complex four-current density

$${}^4\Gamma' = (J_x'; J_y'; J_z'; ic\rho') \tag{18}$$

the continuity equation (6) can be written

$$\text{Div } {}^4\Gamma' = 0 \tag{19}$$

where the operator

$$\text{Div} = \sum_{k=1}^{4} \frac{\partial}{\partial x_k}$$

is called the four-dimensional divergence.

2. The Complex Four-Potential

By means of the complex four-potential

$${}^4\Psi' = \left(A_x'; A_y'; A_z'; \frac{i}{c}\phi'\right) \tag{20}$$

we can re-write Eq. 13

$$\text{Div } {}^4\Psi' = 0. \tag{21}$$

3. The Relations Between the Complex Four-Current Density and the Complex Four-Potential

If we replace the operator $\nabla^2 - \epsilon\mu \cdot \partial^2/\partial t^2$ by the four-dimensional generalization of the Laplace operator

$$\Box = \sum_{k=1}^{4} \frac{\partial^2}{\partial x_k^2}$$

(14) can immediately be re-written

$$\Box {}^4\Psi' = -\mu\, {}^4\Gamma'. \tag{22}$$

This differential equation can be solved (see 6 and 11) and written as follows

$$ {}^{4}\bar{\Psi}' = \frac{\mu}{4\pi^2} \int {}^{4}\Gamma' \frac{d\xi}{R^2} \tag{23} $$

where

$$ R^2 = \sum_{k=1}^{4} (\xi_k - x_k)^2. $$

Equation 23 can be split in two parts, giving Eqs. 12.

4. The Relations Between the Complex Field Six-Vector and the Complex Four-Current Density

Maxwell's equations, Eqs. 4, can be written in the following form:

$$ \left.\begin{aligned} -j\sqrt{\frac{\epsilon}{\mu}}\,\mathrm{curl}\,\bar{Q}' - \epsilon\frac{\partial \bar{Q}'}{\partial t} &= J' \\ i\sqrt{\frac{\epsilon}{\mu}}\cdot\mathrm{div}\,\bar{Q}' &= ic\rho' \end{aligned}\right\} \tag{24} $$

If the components are split, we obtain

$$ \left.\begin{aligned} 0 \quad - j\sqrt{\frac{\epsilon}{\mu}}\cdot\frac{\partial Q_3'}{\partial x_2} + j\sqrt{\frac{\epsilon}{\mu}}\cdot\frac{\partial Q_2'}{\partial x_3} - i\sqrt{\frac{\epsilon}{\mu}}\cdot\frac{\partial Q_1'}{\partial x_4} &= J_x' \\ j\sqrt{\frac{\epsilon}{\mu}}\cdot\frac{\partial Q_3'}{\partial x_1} + \quad 0 \quad - j\sqrt{\frac{\epsilon}{\mu}}\cdot\frac{\partial Q_1'}{\partial x_3} - i\sqrt{\frac{\epsilon}{\mu}}\cdot\frac{\partial Q_2'}{\partial x_4} &= J_y' \\ -j\sqrt{\frac{\epsilon}{\mu}}\cdot\frac{\partial Q_2'}{\partial x_1} + j\sqrt{\frac{\epsilon}{\mu}}\cdot\frac{\partial Q_1'}{\partial x_2} + \quad 0 \quad - i\sqrt{\frac{\epsilon}{\mu}}\cdot\frac{\partial Q_3'}{\partial x_4} &= J_z' \\ i\sqrt{\frac{\epsilon}{\mu}}\cdot\frac{\partial Q_1'}{\partial x_1} + i\sqrt{\frac{\epsilon}{\mu}}\cdot\frac{\partial Q_2'}{\partial x_2} + i\sqrt{\frac{\epsilon}{\mu}}\cdot\frac{\partial Q_3'}{\partial x_3} + \quad 0 \quad &= ic\rho' \end{aligned}\right\} \tag{25} $$

Equations 25 can be interpreted as a "tensor divergence"

$$ \begin{pmatrix} \frac{\partial}{\partial x_1} & \frac{\partial}{\partial x_2} & \frac{\partial}{\partial x_3} & \frac{\partial}{\partial x_4} \\ \frac{\partial}{\partial x_1} & \frac{\partial}{\partial x_2} & \frac{\partial}{\partial x_3} & \frac{\partial}{\partial x_4} \\ \frac{\partial}{\partial x_1} & \frac{\partial}{\partial x_2} & \frac{\partial}{\partial x_3} & \frac{\partial}{\partial x_4} \\ \frac{\partial}{\partial x_1} & \frac{\partial}{\partial x_2} & \frac{\partial}{\partial x_3} & \frac{\partial}{\partial x_4} \end{pmatrix} \tag{26} $$

operating on a complex, antisymmetric field six-vector (or six-tensor), as follows

$$\begin{vmatrix} 0 & -j\sqrt{\frac{\epsilon}{\mu}}\cdot Q_3' & j\sqrt{\frac{\epsilon}{\mu}}\cdot Q_2' & -i\sqrt{\frac{\epsilon}{\mu}}\cdot Q_1' \\ j\sqrt{\frac{\epsilon}{\mu}}\cdot Q_3' & 0 & -j\sqrt{\frac{\epsilon}{\mu}}\cdot Q_1' & -i\sqrt{\frac{\epsilon}{\mu}}\cdot Q_2' \\ -j\sqrt{\frac{\epsilon}{\mu}}\cdot Q_2' & j\sqrt{\frac{\epsilon}{\mu}}\cdot Q_1' & 0 & -i\sqrt{\frac{\epsilon}{\mu}}\cdot Q_3' \\ i\sqrt{\frac{\epsilon}{\mu}}\cdot Q_1' & i\sqrt{\frac{\epsilon}{\mu}}\cdot Q_2' & i\sqrt{\frac{\epsilon}{\mu}}\, Q_3' & 0 \end{vmatrix}. \tag{27}$$

The divergence operator transforms a four-dimensional tensor into a four-vector. It is usually denoted by the symbol **Div**. The complex-field six-vector (27) will be symbolized by $\mathfrak{Q}'$. Thus the tensor (25) can be written

$$\mathbf{Div}\,\mathfrak{Q}' = {}^4\Gamma'. \tag{28}$$

Equation 28 represents Maxwell's equations in their four-dimensional complex form. The system of differential equations, Eq. 28, can be solved (6) and it yields

$$\mathfrak{Q}'(x') = \frac{\mu}{2\pi^2}\int \frac{{}^4\Gamma' \times {}^4\bar{R}}{R^4}\, dv \tag{29}$$

where ${}^4\bar{R}$ is the radius vector from x to x'. The integration is done over the four-dimensional space.

5. The Relationship Between the Complex-Field Six-Vector and the Complex Four-Potential

If Eq. 10 is split into its x, y, z coordinates, we have

$$\left.\begin{aligned} Q_x' &= -\frac{\partial\phi'}{\partial x} + \frac{j}{\sqrt{\epsilon\mu}}\left(\frac{\partial A_x'}{\partial y} - \frac{\partial A_y'}{\partial z}\right) - \frac{\partial A_x'}{dt} \\ Q_y' &= -\frac{\partial\phi'}{\partial y} + \frac{j}{\sqrt{\epsilon\mu}}\left(\frac{\partial A_z'}{\partial z} - \frac{\partial A_x'}{\partial x}\right) - \frac{\partial A_y'}{\partial t} \\ Q_z' &= -\frac{\partial\phi'}{\partial z} + \frac{j}{\sqrt{\epsilon\mu}}\left(\frac{\partial A_y'}{\partial x} - \frac{\partial A_x'}{\partial y}\right) - \frac{\partial A_z'}{\partial t} \end{aligned}\right\}. \tag{30}$$

Introducing the complex four-potential '$\overline{\Psi}$' and the x_k world coordinates these equations can be written

$$\left.\begin{aligned} Q_1' &= \frac{1}{\sqrt{\epsilon\mu}}\left[j\left(\frac{\partial\Psi_3'}{\partial x_2}-\frac{\partial\Psi_2'}{\partial x_3}\right)+i\left(\frac{\partial\Psi_4'}{\partial x_1}-\frac{\partial\Psi_1'}{\partial x_4}\right)\right] \\ Q_2' &= \frac{1}{\sqrt{\epsilon\mu}}\left[j\left(\frac{\partial\Psi_1'}{\partial x_3}-\frac{\partial\Psi_3'}{\partial x_1}\right)+i\left(\frac{\partial\Psi_4'}{\partial x_2}-\frac{\partial\Psi_2'}{\partial x_4}\right)\right] \\ Q_3' &= \frac{1}{\sqrt{\epsilon\mu}}\left[j\left(\frac{\partial\Psi_2'}{\partial x_1}-\frac{\partial\Psi_1'}{\partial x_2}\right)+i\left(\frac{\partial\Psi_4'}{\partial x_3}-\frac{\partial\Psi_3'}{\partial x_4}\right)\right] \end{aligned}\right\}. \tag{31}$$

Inserting these components in the expression for the complex field six-vector $\mathfrak{Q}'$, we obtain

$$\mathfrak{Q}' = \frac{1}{\mu}\left|\begin{array}{cccc} 0 & \left(\frac{\partial\Psi_3'}{\partial x_1}-\frac{\partial\Psi_1'}{\partial x_3}\right)-ij\left(\frac{\partial\Psi_4'}{\partial x_3}-\frac{\partial\Psi_3'}{\partial x_4}\right); & -\left(\frac{\partial\Psi_2'}{\partial x_1}-\frac{\partial\Psi_1'}{\partial x_2}\right)+ij\left(\frac{\partial\Psi_4'}{\partial x_2}-\frac{\partial\Psi_2'}{\partial x_4}\right); & -\left(\frac{\partial\Psi_4'}{\partial x_1}-\frac{\partial\Psi_1'}{\partial x_4}\right)+ij\left(\frac{\partial\Psi_3'}{\partial x_2}-\frac{\partial\Psi_3'}{\partial x_2}\right); \\ -\left(\frac{\partial\Psi_4'}{\partial x_1}-\frac{\partial\Psi_1'}{\partial x_4}\right)+ij\left(\frac{\partial\Psi_4'}{\partial x_3}-\frac{\partial\Psi_3'}{\partial x_4}\right); & 0 & -\left(\frac{\partial\Psi_2'}{\partial x_3}-\frac{\partial\Psi_3'}{\partial x_2}\right)+ij\left(\frac{\partial\Psi_4'}{\partial x_1}-\frac{\partial\Psi_1'}{\partial x_4}\right); & -\left(\frac{\partial\Psi_4'}{\partial x_2}-\frac{\partial\Psi_2'}{\partial x_4}\right)+ij\left(\frac{\partial\Psi_1'}{\partial x_3}-\frac{\partial\Psi_3'}{\partial x_1}\right); \\ \left(\frac{\partial\Psi_1'}{\partial x_3}-\frac{\partial\Psi_3'}{\partial x_1}\right)-ij\left(\frac{\partial\Psi_4'}{\partial x_2}-\frac{\partial\Psi_2'}{\partial x_4}\right); & \left(\frac{\partial\Psi_2'}{\partial x_3}-\frac{\partial\Psi_3'}{\partial x_2}\right)+ij\left(\frac{\partial\Psi_4'}{\partial x_1}-\frac{\partial\Psi_1'}{\partial x_4}\right); & 0 & -\left(\frac{\partial\Psi_4'}{\partial x_2}-\frac{\partial\Psi_2'}{\partial x_4}\right)+ij\left(\frac{\partial\Psi_1'}{\partial x_3}-\frac{\partial\Psi_3'}{\partial x_1}\right); \\ \left(\frac{\partial\Psi_4'}{\partial x_1}-\frac{\partial\Psi_1'}{\partial x_4}\right)+ij\left(\frac{\partial\Psi_3'}{\partial x_2}-\frac{\partial\Psi_2'}{\partial x_3}\right); & -\left(\frac{\partial\Psi_4'}{\partial x_2}-\frac{\partial\Psi_2'}{\partial x_4}\right)+ij\left(\frac{\partial\Psi_1'}{\partial x_3}-\frac{\partial\Psi_3'}{\partial x_1}\right); & \left(\frac{\partial\Psi_2'}{\partial x_1}-\frac{\partial\Psi_1'}{\partial x_2}\right)+ij\left(\frac{\partial\Psi_4'}{\partial x_3}-\frac{\partial\Psi_3'}{\partial x_4}\right); & 0 \end{array}\right| \tag{32}$$

This six-vector can be split up as follows:

$$\mathfrak{Q}' = \frac{1}{\mu}\left|\begin{array}{cccc} 0 & \frac{\partial\Psi_2'}{\partial x_1}-\frac{\partial\Psi_1'}{\partial x_2}; & \frac{\partial\Psi_3'}{\partial x_1}-\frac{\partial\Psi_1'}{\partial x_3}; & \frac{\partial\Psi_4'}{\partial x_1}-\frac{\partial\Psi_1'}{\partial x_4} \\ \frac{\partial\Psi_1'}{\partial x_2}-\frac{\partial\Psi_2'}{\partial x_1}; & 0 & \frac{\partial\Psi_3'}{\partial x_2}-\frac{\partial\Psi_2'}{\partial x_3}; & \frac{\partial\Psi_4'}{\partial x_2}-\frac{\partial\Psi_2'}{\partial x_4} \\ \frac{\partial\Psi_1'}{\partial x_3}-\frac{\partial\Psi_3'}{\partial x_1}; & \frac{\partial\Psi_2'}{\partial x_3}-\frac{\partial\Psi_3'}{\partial x_2}; & 0 & \frac{\partial\Psi_4'}{\partial x_3}-\frac{\partial\Psi_3'}{\partial x_4} \\ \frac{\partial\Psi_1'}{\partial x_4}-\frac{\partial\Psi_4'}{\partial x_1}; & \frac{\partial\Psi_2'}{\partial x_4}-\frac{\partial\Psi_4'}{\partial x_2}; & \frac{\partial\Psi_3'}{\partial x_4}-\frac{\partial\Psi_4'}{\partial x_3}; & 0 \end{array}\right| \tag{Cont.}$$

$$-\frac{ij}{\mu}\begin{vmatrix} 0 & ; \frac{\partial \Psi_4'}{\partial x_3} - \frac{\partial \Psi_3'}{\partial x_4} ; \frac{\partial \Psi_2'}{\partial x_4} - \frac{\partial \Psi_4'}{\partial x_2} ; \frac{\partial \Psi_3'}{\partial x_2} - \frac{\partial \Psi_2'}{\partial x_3} \\ \frac{\partial \Psi_3'}{\partial x_4} - \frac{\partial \Psi_4'}{\partial x_3} ; & 0 & ; \frac{\partial \Psi_4'}{\partial x_1} - \frac{\partial \Psi_1'}{\partial x_4} ; \frac{\partial \Psi_1'}{\partial x_3} - \frac{\partial \Psi_3'}{\partial x_1} \\ \frac{\partial \Psi_4'}{\partial x_2} - \frac{\partial \Psi_2'}{\partial x_4} ; \frac{\partial \Psi_1'}{\partial x_4} - \frac{\partial \Psi_4'}{\partial x_1} ; & 0 & ; \frac{\partial \Psi_2'}{\partial x_1} - \frac{\partial \Psi_1'}{\partial x_2} \\ \frac{\partial \Psi_2'}{\partial x_3} - \frac{\partial \Psi_3'}{\partial x_2} ; \frac{\partial \Psi_3'}{\partial x_1} - \frac{\partial \Psi_1'}{\partial x_3} ; \frac{\partial \Psi_1'}{\partial x_2} - \frac{\partial \Psi_2'}{\partial x_1} ; & 0 & \end{vmatrix} \tag{33}$$

$$= \frac{1}{\mu}(\mathfrak{Q}_1' - ij\mathfrak{Q}_2').$$

The complex six-vector $\mathfrak{Q}_1'$ is immediately recognized as the four-dimensional curl of the complex four-potential. Thus

$$\mathfrak{Q}_1' = \operatorname{curl} {}^4\bar{\Psi}'. \tag{34}$$

To analyze $\mathfrak{Q}_2'$ we perform the following operations. If we substitute in the vector (27) the components of $\bar{Q}' = \bar{E} + j\sqrt{\frac{\mu}{\epsilon}}\,\bar{H}$, we obtain

$$\mathfrak{Q}' = \begin{vmatrix} 0; & H_3; & -H_2; & -icD_1 \\ -H_3; & 0; & H_1; & -icD_2 \\ H_2; & -H_1; & 0; & -icD_3 \\ icD_1; & icD_2; & icD_3; & 0 \end{vmatrix} - ij \begin{vmatrix} 0; & -icD_3; & icD_2; & H_1 \\ icD_3; & 0; & -icD_1; & H_2 \\ -icD_2; & icD_1; & 0; & H_3 \\ -H_1; & -H_2; & -H_3; & 0 \end{vmatrix}. \tag{35}$$

These two six-vectors are called ${}^2\mathbf{G} = (\bar{H}, -ic\bar{D})$ and ${}^2\mathbf{G}^* = (-ic\bar{D}, \bar{H})$ by Stratton (6). The six-vector ${}^2\mathbf{G}^*$ is called the "dual" six-vector of ${}^2\mathbf{G}$, and it is obtained from ${}^2\mathbf{G}$ by an exchange of the real and imaginary constituents with respect to the relativistic separating factor i, that is, $G_{23} = G^*_{14}$; $G_{34} = G^*_{12}$; $G_{42} = G^*_{13}$. Thus

$$\mathfrak{Q}_2' = \mathfrak{Q}_1'^* = [\operatorname{Curl} {}^4\bar{\Psi}']^*. \tag{36}$$

Therefore

$$\mathfrak{Q}' = \frac{1}{\mu}\{\operatorname{Curl} {}^4\bar{\Psi}' - ij\,[\operatorname{Curl} {}^4\bar{\Psi}']^*\}. \tag{37}$$

6. Summary

The diagram of Fig. 1 can now be compressed to the diagram of Fig. 2 in which Ω' represents the complex field six-vector, $^4\Gamma'$ represents the complex four-current density and $^4\Psi'$ is the complex four-potential. The different relations between these quantities are shown in the diagram of Fig. 3.

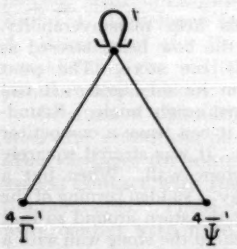


FIG. 2. Schematic diagram showing the connection between the complex, four-dimensional quantities introduced.

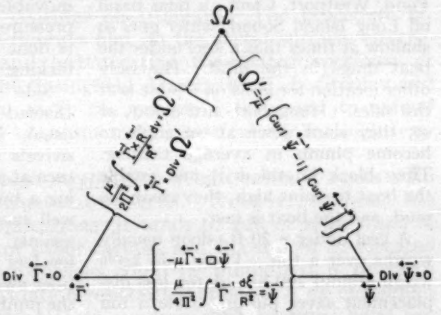


FIG. 3. The classical electromagnetic equations expressed as complex, four-dimensional quantities.

REFERENCES

(1) H. WEBER, "Die partiellen Differential-Gleichungen der mathematischen Physik nach Riemann's Vorlesungen," 4 Auf., 2 bd., Braunschweig, Vieweg, 1901.
(2) L. SILBERSTEIN, "Elektromagnetische Grundgleichungen in bivektoriellen Behandlung," *Ann. Physik*, Vol. 22, pp. 579–586 (1907).
(3) L. SILBERSTEIN, "Nachtrag zur Abhandlung über elektromagnetische Grundgleichungen in bivektoriellen Behandlung," *Ibid.*, Vol. 24, pp. 783–784 (1907).
(4) L. SILBERSTEIN, "Quaternionic Form of Relativity," *Phil. Mag.*, Vol. 23, pp. 790–809 (1912).
(5) H. BATEMAN, "The Mathematical Analysis of Electrical and Optical Wave-Motion on the Basis of Maxwell's Equations," New York, Cambridge University Press, 1915.
(6) J. A. STRATTON, "Electromagnetic Theory," 1st ed., New York, McGraw-Hill Book Co., Inc., 1941.
(7) H. MINKOWSKI, "Raum und Zeit," *Physik. Z.*, Vol. 10, pp. 104–111 (1909).
(8) H. MINKOWSKI, "Die Grundgleichungen für die elektromagnetischen Vorgänge in bewegten Körpern," *Math. Ann.*, Vol. 68, pp. 472–525 (1910).
(9) A. SOMMERFELD, "Zur Relativitätstheorie, I, Vierdimensionale Vektoralgebra," *Ann. Physik*, Vol. 32, pp. 749–776 (1910).
(10) A. SOMMERFELD, "Zur Relativitätstheorie, II, Vierdimensionale Vektoralgebra," *Ibid.*, Vol. 33, pp. 649–689 (1910).
(11) A. SOMMERFELD, "Electrodynamics," New York, Academic Press, Inc., 1952.
(12) S. A. SCHELKUNOFF, "Electromagnetic Waves," New York, D. Van Nostrand Company, Inc., 1943.

Sailing Keels,* A New Design in Sailing Vessels.—The most important elements of this boat are its sails and its keels.

Perhaps we are discussing the dawn of a new era in yachting. This 20-ft. sail punt has keels at its sides instead of on the bottom. On Sherwood Pond, Westport, Conn., a tidal basin off Long Island Sound, water gets so shallow at times that a keel under the boat drags in the mud. The only other location for keels on a punt is at the sides. Hung outboard a foot or so, they slant down at an angle to become plumb in average tacking. They block lateral drift and enable the boat to point high, they clear the mud, and the boat is fast.

A keel under a 20 ft. sloop usually weighs over a ton. These side keels weigh around 200 lb. A ton less displacement saves pushing aside a ton of water in sailing.

A side keel is a thin flat blade, sled shaped, 6 ft. long and 18 in. deep. The energy exerted slicing through the water is measured in ounces. The underwater body is sharp at both ends. The punt is built of $\frac{3}{8}$-in. "exterior mahogany" plywood. The flat bottom member and the flat side members meet at the bilges. Planes through bilges are parallel to the side keels.

A cast bow member attached above water gives the profile of the usual yacht bow. Beam amidships is 4 ft. It can be more.

As the punt heels over in tacking, centers of buoyancy and of displacement shift from the middle to a lee corner or bilge (which can't happen with a rounded bottom). *Sailing Keels* has a stiff resistance to heeling due to leverages involved. Its sails, being more erect, have greater driving power.

In a heeling boat the usual rudder tends either to lift the stern or depress it, thus exerting a drag. To avoid it the rudder post needs to be plumb, movable by hand but not by water pressure as shown in Hill patents. It is done by a touch of the elbow in tacking.

Side keels help maneuverability. Instead of the bow being steered as usual, it is the stern. The punt swivels upon its side keels. It can turn at almost a right angle. Rounding a buoy it can leave a competitor well astern. It was steered squarely against a stone wall. When but a few feet away, a sudden turning of the tiller swung the stern around so that the punt cleared the stone wall with a yard to spare. It facilitates tacking. Jockeying can be a nerve strain on rivals.

Side keels prevent capsizing. During a race upon the Sound between *Lightning* type yachts, a storm with a black cloud appeared. A gust played havoc with the racers. It hit *Sailing Keels* and crashed her mast in four pieces. Her windward keel lifted out of water but she didn't capsize. A duplicate mast (of Yukon spruce) was then covered with fiberglass. When the main sheet slipped overboard the sail hung from the mast head billowed to leeward. The mast bent over like a fishing pole, then straightened up. Fiberglass is said to increase strength some six times.

No skilled shipbuilder is needed to build *Sailing Keels*. One skilled with a hammer, saw, drill and a pot of Penetrol can build it. The usual yacht paint may then be applied.

The boat built by the writer in his side yard is open to inspection.

* EDITOR'S NOTE: Dr. Myron Francis Hill, of Westport Conn., developed the sailing keels herein described and, at our request, wrote this description of his boat for the JOURNAL.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS

PROTECTIVE COATINGS FOR TITANIUM

The National Bureau of Standards has successfully electrodeposited hard, adherent protective coatings on titanium. The procedure involves forming a titanium fluoride film on the metal surface, electroplating with chromium, and heat-treating the plated specimen at 800° C.[1] Developed for the Springfield Armory by C. L. Stanley and A. Brenner of the Bureau staff, the process is expected to extend considerably the utility of titanium metal, particularly for high-temperature applications.

Because of titanium's high strength-to-weight ratio, it ranks with steel and aluminum as a structural material. However, titanium has disadvantages for some applications: it tends to gall or seize when in loaded contact with itself or other metals, and it oxidizes at elevated temperatures. These disadvantages could be minimized if titanium were coated with hard, oxidation-resistant metals such as chromium or nickel, but previous attempts to produce such coatings have not been entirely successful. Although the Bureau had obtained good adhesion of aluminum to titanium in an earlier investigation using a nonaqueous plating bath, the method was not suitable for job-shop applications and the results were not sufficiently consistent.

The main problem in depositing metals on titanium is lack of adhesion—some deposits have actually exfoliated during the plating operation and others have been easily pulled off with the fingers. Poor adhesion has been blamed on an oxide film on the base metal, but attempts to remove the suspected film with acid etches or anodic films were not successful. For this reason, the present investigation included a study of the influence of oxide films and methods to remove them.

In a preliminary investigation, the Bureau designed an experiment intended to remove any oxide film and to plate the titanium specimen before it could reoxidize. In this procedure, a small piece of titanium was enclosed in an evacuated tube containing silicon carbide and ceramic balls. The tube was tumbled for several hours to abrade the metal surface and then placed in a chromium plating bath, where it was crushed so as to expose the metal specimen to the bath before the atmosphere could touch it. In a control experiment, a titanium specimen was similarly abraded in an open tube. The adhesion of the

[1] For further technical details, see "The Adhesion of Electroplated Coatings to Titanium," by Connie L. Stanley and Abner Brenner, *Tech. Proc. Am. Electroplater's Soc.* 1956.

first specimen was distinctly better than that of the control, supporting the hypothesis that a film, probably an oxide, exists on the surface of titanium and impairs adhesion of metal deposits.

The Bureau investigated a number of etching and plating procedures and obtained the best chromium plates by pretreating titanium to form a coating of titanium fluoride before plating the specimen. This procedure appears to prevent the formation of an oxide and, when the specimen is placed in the plating bath, the titanium fluoride dissolves permitting the chromium to bond directly to the basis metal.

Titanium specimens are thoroughly degreased and cleaned before this treatment. Next they are dried and suspended in a solution of hydrofluoric and acetic acids. After 10 or 15 min. a 60-cycle alternating current is passed through the specimen for another 10 min. The specimens are then rinsed and transferred to a conventional chromium plating bath, where they are plated at a temperature of 85° C. and a current density of 120 amp/dm^2.

Chemical analysis indicates that the film produced by the preliminary acid treatment contains a low valence titanium compound. A sample of the dried film contained 37 per cent of titanium and 54 per cent of fluorine, and examination by X-ray diffraction showed no lines characteristic of titanium tetrafluoride.

Tensile strength tests indicate that adherence of the chromium coating to titanium is greatly improved by heat-treating the plated specimen for two minutes at 800° C. in an inert atmosphere. Coating adhesion was determined by the nodule method.[2] Essentially this procedure consists in electrodepositing a cobalt nodule, $\frac{1}{16}$ in. in diameter, on the coating and then determining the force necessary to detach the nodule together with the coating from the basis metal. The bond strength of the heat-treated specimens ranged from 4000 to 18,000 psi. Although the highest value obtained is somewhat below the tensile strength of heat-treated chromium, fracture occurred in all cases in the chromium plate and not between the two metals.

Coatings on titanium consisting of 0.02 mm. of chromium plus 0.15 mm. of nickel were found to be moderately adherent without heat treatment, but not comparable to that of chromium on steel. If such specimens 0.5 in. wide are broken by repeated bending, the chromium-nickel coatings can be stripped from the titanium with a force of about 10 lb.

Procedures for depositing nickel and copper on titanium have been formulated that are similar to the process for depositing chromium. However, the nickel and copper deposits have not adhered as well as chromium and have frequently blistered.

[2] See "The Nodule Method of Measuring the Adhesion of Electrodeposited Coatings," by Abner Brenner and Virginia D. Hills, *Proc. Am. Electroplaters Soc.*, Vol. 37, p. 51 (1950); also "Nodule Method Measures Adhesion of Electrodeposits," *NBS Tech. News Bull.*, Vol. 34, p. 80 (1951).

APPARATUS FOR ETCHING FINE POINTS

An improved method for producing fine points by electrolytic etching of wire under tension has been developed at the National Bureau of Standards. Although these points were constructed for use as electron sources for a field emission X-ray microscope, they could also be used as field-emission ion sources to replace the thermionic emitters in accelerators and mass spectrographs. The improved process was developed by R. C. Placious and R. A. Schrack of the Bureau's electron physics laboratory as part of a project for the Air Research and Development Command.

The apparatus is similar to that developed by Niemeck and Ruppin for the electrolytic etching of points under tension, but improves the original design by employing a tensiometer to preset tension to a known value. With the accurate determination of tension, control of point size and geometry becomes possible. A high tension causes the wire to break in a shorter time and produces a larger point than a low tension with a longer etching period. Current-voltage characteristics of the points as field emitters can be quite accurately predicted on the basis of the tension applied during etching, since the size of the point determines the current emission at a particular voltage.

A tensiometer consisting of a fine wire spring in a calibrated glass tube is mounted on a vertically adjustable arm. To preset the tension, one end of the calibrating spring is temporarily fastened to a tension spring mounted on the apparatus directly below the tensiometer. The desired tension on the tensiometer spring is obtained by adjusting both the vertical position of the arm and the extension of the tension spring. A pointer clamped to the arm marks the point of contact between the calibrating and the tension springs at the final tension adjustment. Also attached to the arm is a nickel wire loop containing a film of electrolytic solution. The point is formed where the wire passes through the film.

When the desired tension has been obtained, the tensiometer is replaced by a chuck holding a metal shank to which the wire to be etched is welded. A crosspiece spotwelded to the metal shank positions the wire in the etching plane and also serves as a stop for locating the shank in the chuck. After the point has been formed this crosspiece will locate it in the field emission equipment with minimum adjustment. Attaching the tension spring to the wire at the position indicated by the pointer places the wire under the same tension set by the tensiometer.

It is important to clean the wire before etching, and isolating the equipment from vibration and air currents aids in obtaining symmetrically etched points. Any size wire can be used but the Bureau's points were etched from 5 or 6 mil diameter tungsten wire in a 0.6 normal sodium hydroxide electrolyte. The electrolyte is inserted with an eyedropper into the nickel wire loop through which the tungsten

wire passes, and 8 to 10 v d.c. is applied so that the conventional direction of current flow is from the wire to the loop. Varying the amount of electrolyte in the loop controls this current; it is initially adjusted to 2 ma for tungsten and drops to about 0.5 ma just before breaking. Etching takes about 15 min. The current values and time are not critical.

NOTE: For further technical details, see "Apparatus for Etching Fine Points Under Controlled Conditions," by R. A. Schrack and R. C. Placious, *Rev. Sci. Instr.*, Vol. 26, p. 412 (June 1956).

TO MEMBERS AND THOSE WHO KNOW THE FRANKLIN INSTITUTE

All of us associated with The Franklin Institute are gratified by the support given by its benefactors in the past. Without their generosity our privately endowed Institute would have been unable to serve industry, the professions, and the public as it has and should.

There is still a continuing and pressing need of contributions and bequests —both for general and specific endowment, and of income to be judiciously used. Your response will be most earnestly appreciated.

Checks should be made payable to The Franklin Institute, and sent to The Franklin Institute, Benjamin Franklin Parkway at 20th Street, Philadelphia 3, Pennsylvania.

Where property is transferred, title should be in the name of The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts.

We shall be glad to supply any additional information regarding gifts and memorials. Please write to the above address, attention of the Endowment Department.

THE FRANKLIN INSTITUTE

ANNUAL REPORT OF THE BOARD OF MANAGERS FOR THE YEAR 1956 *

SUMMARY

In an annual report for an organization such as The Franklin Institute, much of the work of which continues from year to year, it is customary to point out comparisons with previous years. The Institute as a whole had a successful year in 1956 and it went forward in all phases of its work. At the same time it is possible to expect further progress; and so some of the aspirations for the year ahead will be mentioned in the individual sections—after a brief resume of the whole.

Museum attendance showed a further increase, continuing an upward trend that started five years ago. About 132,000 of the total of 336,000 visitors were in groups of school children. For some of them the Museum Education Division arranged special programs designed to interest young people in careers in science and engineering, as part of the Institute's effort to help alleviate the national shortage of trained people in these professions.

Research activities made significant contributions to knowledge. At the Bartol Research Foundation they concerned low-energy nuclear physics, cosmic-ray surveys, and selected topics in solid state physics. At the Laboratories for Research and Development the gross value of the wide range of investigations for industrial sponsors and the U. S. Government exceeded $3 million for the first time. The greatest increase in effort occurred in the field of nuclear engineering, and near the close of the year a separate division of the Laboratories was created to handle this work.

The work of the Committee on Science and the Arts culminated in the award of six medals at the annual Medal Day ceremonies in October. In addition to the usual series of scientific lectures throughout the year, two symposia attracted persons from all parts of the country.

The major new equipment acquired comprises a Univac Computing System and an analog computer, which have given the Laboratories the basis of a well-rounded computation service. Making room for the Univac required shifting the Museum offices to the third floor, where superior facilities have been provided. Also a classroom has been equipped for the Museum Education Division.

The principal change in staff was the retirement of Dr. Henry B. Allen

* This summary was presented at the Annual Meeting, January 16, 1957, by the President, S. Wyman Rolph.

at the end of January after twenty years of service as the operational head of the Institute. He was succeeded by Dr. John S. Burlew. Additional employees were obtained for the Laboratories, so that the total technical personnel there amounted to 259 at the end of the year.

Financially speaking, the year 1956 was a better one for The Franklin Institute. The Laboratories not only were self-supporting, but they accumulated a surplus that can be used for the purchase of much needed equipment. The inevitable deficit from the educational activities of the Institute was partially made up by gifts totaling $45,000 from nearly 450 "Friends of Franklin."

A special event that marked this year of 1956 was the celebration of the 250th anniversary of the birth of Benjamin Franklin. One feature was a special anniversary issue of the JOURNAL *that appeared in January. A committee of the Institute spearheaded a world-wide celebration, some phases of which took place at the Institute itself. The work of this committee, and particularly that of its chairman, Mr. Clarence L. Jordan, resulted in an unprecedented amount of publicity, not only for the memory of Benjamin Franklin, but also for The Franklin Institute.*

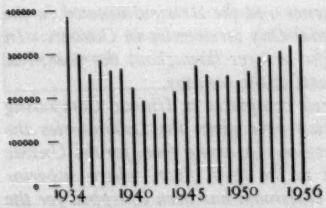
MUSEUM

Visitors

The number of visitors to the Museum exceeded 300,000 for the second successive year, as shown by the following statistics:

	Total	Paid	Free	Planetarium	Nickelodeon
1956	336,270	257,704	78,566	240,577	49,675
1955	312,013	227,361	84,652	214,562	64,815

In 1956, about 72 per cent of the visitors went to the Planetarium and about 15 per cent went to the Nickelodeon, which had been opened in January 1955.



Graph showing Museum attendance since 1934. (The increase in total attendance continues a trend that started in 1951, with the total now approaching the all-time high set in 1934, the year the Museum was opened.)

On three days the attendance exceeded 2500 because of large groups of visitors who came on railroad excursions. Also on one day during Latin Week the attendance exceeded 2500. There have been only six other occasions in the past ten years when the attendance on any one day exceeded 2500.

For the first time a record has been kept of "collateral attendance," comprising persons who have visited the building to attend a non-Museum function or who

have attended a Museum-sponsored function outside of regular Museum hours. The total of 46,326 such visitors represents 13.7 per cent of the regular attendance listed above.

The first of a new series of Museum events took place in October. This was an Open House evening at the Museum, sponsored by some of the principal Museum exhibitors. The guests on that occasion were some 215 members of Rotary Clubs in Philadelphia and neighboring communities.

Atomic Energy educational films were shown to Museum visitors on week-ends. Ten different films were shown with a total audience of 5836.

Exhibits

Four new exhibit cases presenting an illustrated biography of Benjamin Franklin were displayed for the first time in Franklin Hall on Franklin's birthday, January 17. These cases have loudspeakers built in and provide a quality public address system for Franklin Hall. By the use of eight loudspeakers in the room instead of two, the volume required from each is sufficiently reduced that there is a marked improvement in the acoustics.

A visual earthquake recorder, lent by the U. S. Coast and Geodetic Survey, was installed in the Planetarium Lobby. It is in continuous operation and records, on a paper chart mounted on a drum, earth tremors picked up by the seismograph located in the basement. One unusual tremor recorded at 8:05 p.m. on the evening of March 28 was caused by the explosion of the Tidewater Grain Company's elevator on Market Street, about a mile from the Institute.

Two temporary exhibits in the Planetarium Lobby attracted a great deal of attention. One was a model of a three-stage rocket, such as is to be used in the firing of the earth satellite. The other was a hurricane plotting board, operated for about four months in cooperation with the U. S. Weather Bureau. It will be displayed again beginning July 1957.

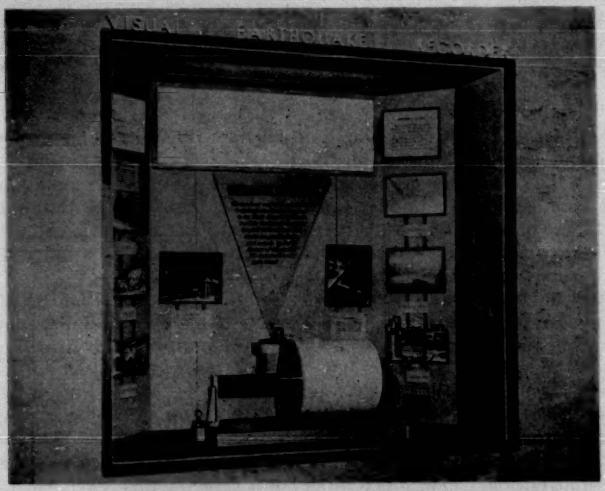
The attractiveness of the Marine Room was increased by the addition of new colored backgrounds for the ship models, new labels, and some rearrangement of the exhibits. A large globe was installed at the head of the main staircase to show the routes followed by the principal maritime discoverers. A new exhibit was installed in the Graphic Arts Room explaining the principles of the four major printing processes.

A small display to show the development of power, from animal power to the steam turbine, was arranged on the ground floor near the Lounge. The exhibits for it were saved from the old Prime Movers Room, which was cleared for the installation of the Univac.

Construction of the HO gage model railroad continued during the year. Visitors enjoyed watching the creation of the scenic backgrounds that are to give the illusion of reality to the several trains running on

more than 900 feet of track. This installation is expected to be completed by early fall of 1957.

Planning of future exhibits was concentrated on an exhibit showing the principles of electrical conductivity with special emphasis on transistors; on a large integrated exhibit dealing with basic chemistry; and on a computation exhibit the focal point of which will be a view of the Institute's new Univac Computing Center to be opened in January 1957.



Visual earthquake recorder—only one in the Philadelphia area—installed in the Planetarium lobby.

MUSEUM—PLANETARIUM

A number of Planetarium shows specifically designed for school children of varying ages and interests were offered and produced, in addition to the regularly scheduled shows. Some were accompanied by special events. Thus, on two evenings during Latin Week, high school students staged a Roman Festival at the conclusion of the Planetarium demonstration. These festivals culminated in Roman banquets in Franklin Hall. Attendance at the two festivals was 1081.

Because of the great public interest in the close approach of Mars to the earth in September, a series of six special evening shows of *Rocket to Mars* was arranged. They included observation of Mars from the Observatory on the roof of the Institute building. A total of 1359 visitors attended these six Mars shows.

Planetarium Shows During 1956.

Subject	Months
**Poor Richard's Almanac*	January
Once in a Blue Moon	February
Reasons for the Seasons	March
Rocket to Mars	April–May
	August–September
The Sun—The Earth's Powerhouse	June
Mid-Summer Night	July
**Jet Streams and Hurricanes*	October
The Expanding Universe	November
Star of Bethlehem	December

* Presented for the first time in 1956.

Members of the staff of the Planetarium presented a course of nine evening public lectures on "Astronomy for Everyone" during March and April. Enrollment was 211 persons and total attendance for the series was 930.

MUSEUM—SCIENCE EDUCATION

Nearly all aspects of the Museum contribute to science education, but certain activities arranged for by the Division of Museum Education deserve special mention in this connection.

The regularly scheduled visits by school children—131,693 of them in 1956—during regular school hours have as their aim the introduction of young people to the interesting world of science. Many of these visits include the Planetarium, where lecture-demonstrations specially prepared for pupils in the elementary grades are presented. A new lecture-demonstration in this series started during 1956 dealt with geography, for which the setting of the Planetarium is well suited. In addition, about 26,000 other children visited the Museum in groups.

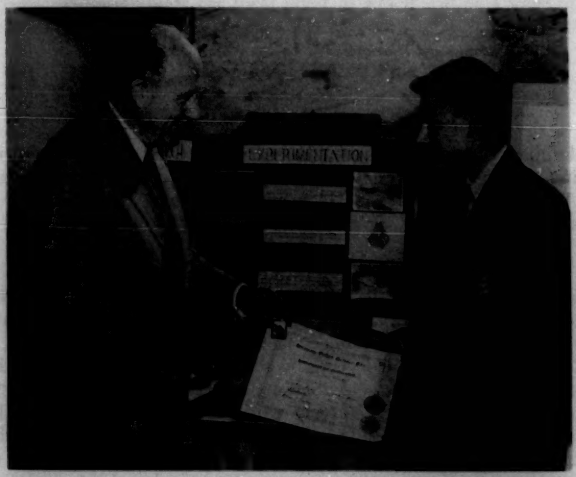
Lectures

Another new lecture-demonstration dealt with "The Science of Music." This was presented in the Lecture Hall on three occasions in November to capacity audiences of students from junior and senior high schools. The usual special demonstrations during Fire Prevention Week in October were presented by representatives of the City of Philadelphia Fire Department. 1565 children attended these (seven) demonstrations.

The annual James Mapes Dodge Lecture for Young People was presented on October 30 by Dr. Eric M. Rogers, Professor of Physics at Princeton University. His two-hour demonstration on "Nuclear Physics—Its Tools at Work" held the attention of 390 boys and girls from schools (predominantly high schools) throughout the metropolitan area.

Science Fair

The annual Science Fair, co-sponsored by the *Philadelphia Inquirer* and The Franklin Institute, was held in Franklin Hall on April 7 to 10, inclusive. The nearly 400 exhibits submitted by students of all ages



Alan Kolber, receiving from Mr. Rolph the top award of the Science Fair held at the Institute.

reflected a very wide range of interest from a "Cardioscope" to "Fusion Source of Solar Energy."

Workshops

Workshop programs for young people have been conducted by the Institute for many years. The summer workshop in 1956 was attended by 73 boys and girls, divided into junior and senior groups which met two days a week for five weeks. They had the advantage of using the new classroom. Two Winter Workshop programs were conducted in the 1955–1956 season, each of 20 Saturday sessions, with 46 students enrolled. Similar programs were initiated on November 17, 1956.

Career Guidance

A career guidance program was staged at the Institute by the Engineering and Technical Societies Council in April. A motion picture on careers in engineering and direct counselling from qualified

engineers attracted 79 junior and senior high school boys. Another phase of this career guidance service was supplying schools with career information and having the Institute serve as a liaison between the schools and the speakers bureau set up by the Council.

Another important effort in career counselling was a continuation of a program of career forums started in the spring of 1955. A forum dealing with careers in chemistry was conducted on November 14 with 416 junior high school students from 20 schools in the metropolitan area. It was sponsored by the American Chemical Society and the American Institute of Chemical Engineers, in cooperation with the Institute.

The Franklin Institute Squadron of the Civil Air Patrol has been sponsored by the Institute through its Division of Museum Education. At the weekly meetings, held in the Institute's classroom, instruction is given in the principles of aviation, electronics, and other technical subjects. On December 1, when the Squadron celebrated its first anniversary, it had 70 cadets plus six adult leaders.

LIBRARY

During the year approximately 5980 persons made personal use of the Library and 4685 telephone requests for information were handled.

Some 3400 new books were added to the collection and subscriptions were started for 20 new serial publications.

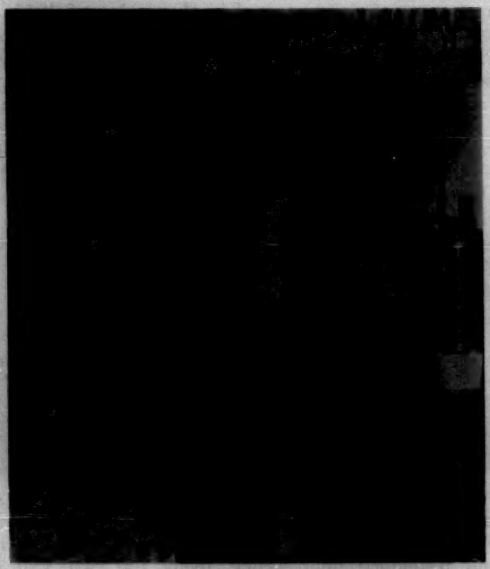
Gifts totaling $900 were received for the purpose of strengthening the chemistry division of the Library.

THE BARTOL RESEARCH FOUNDATION

The Bartol Research Foundation continued its researches along lines pertaining to neutron scattering (elastic and inelastic), radioactivity, and resonance fluorescence, using the two Van de Graaff generators, the Cockcroft-Walton set, the proton spectrometer, and the beta-ray spectrometer, which are all valuable components of the laboratory's coordinated equipment for research in nuclear physics. The general purposes of these researches is the determination of fundamental characteristics of the atomic nuclei in their various aspects. Certain theoretical work in nuclear physics is also in progress.

In the cosmic-ray field, participation in the program of the International Geophysical Year is proceeding, in the form of measurements of neutron intensity at different latitudes and longitudes over the ocean, and also at high altitudes. The Foundation has a place in the earth satellite program and a place in the programs sponsored by the International Geophysical Year for flying photographic plates at high altitudes with the object of examining the incoming cosmic-ray particles. It is also participating in the work at a cosmic-ray station at Thule, Greenland.

Researches in secondary emission of electrons from solid surfaces, and of electrical conductivity induced by electron bombardment are in progress, along with studies of the electrical properties of ionic crystals. A special two-million volt Van de Graff generator for the prosecution



The target end of the large Van de Graaff generator at the Bartol Research Foundation. The generator itself towers some 40 feet above the left end of the picture.

of this work, and sponsored by the Office of Ordnance Research, is in process of construction.

The number of papers published during the last year amounted to nineteen.

LABORATORIES FOR RESEARCH AND DEVELOPMENT

The Franklin Institute Laboratories for Research and Development had their tenth anniversary in March. During these ten years there have been constant growth and expansion of research services with an increase of research personnel to 259 scientists and engineers from diverse fields.

The total volume of business, which has been increasing during this ten-year period, reached a new high in 1956, as shown in the accompanying table.

Value of Sponsored Research Projects.

	1956	1955	1954
Industrial Projects	$1,125,000	$ 661,637	$ 714,569
Government Projects	$2,105,000	$2,096,888	$2,185,047
Total	$3,230,000	$2,758,525	$2,899,616

The very large increase in industrially sponsored projects is especially encouraging because its confirms the assumption made when the Laboratories were founded, that they would grow into an important asset in the industrial life of the community.

Most of the results of this research and development must be kept secret, either to guard military security or to protect the competitive position of industrial sponsors. Nevertheless, some projects result in new information that can be published. During the first ten years there were 158 articles published by staff members of the Laboratories on subjects listed in the accompanying table.

Publications from the Laboratories.

	1956	1947–1956
Bioengineering	1	3
Chemistry	10	45
Electrical Engineering, Electronics	4	35
Mechanical Engineering	5	30
Metals Research	20	43
Nuclear Engineering	1	2
Total	41	158

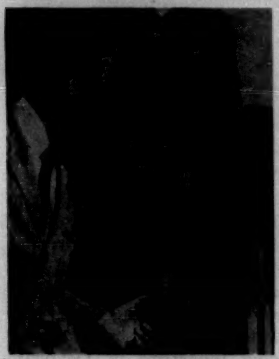
Activities in the field of nuclear research warranted the creation in November of a separate division—the Nuclear Engineering Division—designed to increase the Laboratories' ability to render service to the government and to the rapidly expanding industries in Delaware Valley. The first work in the nuclear field had been started only two years previously with one project in the Mechanical Engineering Division.

Work in air pollution has been expanding in the Division of Chemistry and Physics. A mobile laboratory, for analysis of polluted air,

and a team of scientists were sent in August to Pasadena, California, to study the smog problem in the Los Angeles area. This thirty-five foot trailer contains a special long-path infrared absorption cell and spectrometer designed and constructed by Laboratory personnel under

Exterior and interior views of the Institute's mobile air pollution laboratory.

the sponsorship of the American Petroleum Institute. This particular program will continue in 1957 and promises to contribute much to our understanding of air pollution problems and their alleviation.



Zone refining apparatus used in the Laboratories to purify metals of high melting point.

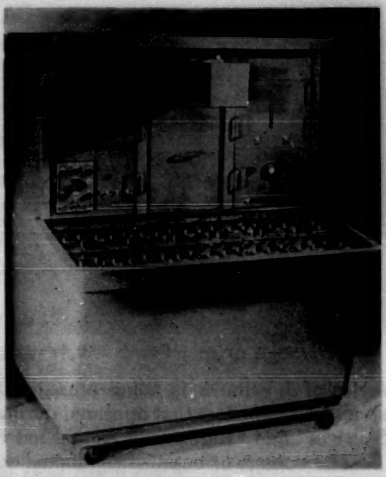
During Cleaner Air Week in Philadelphia in October, a public semi-technical symposium was held at the Institute under the auspices of the Laboratories. It was designed primarily to clarify the present approaches to the problem and outline steps that have yet to be taken to ensure cleaner air for our cities. The program also featured a tour of the Institute's air pollution research laboratory and an exhibit dealing with equipment and methods for research.

Work in metallurgy in the Division of Solid State Physics is receiving international recognition. However, due to lack of space and equipment, the desired expansion in this field has had to be postponed.

The recording of transient events in proper time sequence is important in the study of mechanical strains and in chemical kinetics. An electronic recorder for this pur-

pose has been developed by the Electronics Section of the Electrical Engineering Division in a project sponsored by the Army Ordnance Corps. This new recorder is not only less expensive than the drum camera formerly used, but also it is more versatile in that the time resolution may be varied to expand critical portions of the record.

A Remington-Rand Univac digital computer system, complete with a high-speed printer and other peripheral equipment, was installed. By the end of the year it had had several weeks of check-out operation and was ready for routine use. It will be operated by personnel from the



Twelve-channel sequential event recorder, designed and constructed in the Laboratories.

Model of the Univac system installed as part of the Institute's computation facilities.

Analysis Section of the Electrical Engineering Division. It will be used to solve engineering problems that arise from projects in various sections of the Laboratories and also will be available for data processing for other organizations. It is the first Univac computer system to be installed in a private research institute for public use.

The Projection Magnifier as manufactured for sale.

A Projection Magnifier, which enables a partially sighted person to read books and magazines, had been developed several years ago by the Bioengineering Section under contract with the Kellogg Foundation. During 1956 it was put into commercial production by the American Optical Company, and can now be purchased by the general public.

In an effort to make the facilities of the Laboratories better known to industry, a series of brochures is being prepared for distribution to prospective sponsors. The two that appeared during 1956 dealt with "Computation Services" and "Industrial Colloids and Polymers."

The volume of business conducted during 1956 is about a maximum for the space now occupied by the Laboratories. No more space is available in the present Institute buildings and so the Board of Managers, through a special committee, has been seeking a suitable building that will house all the activities of the Laboratories and provide room for further growth.

MEETINGS

The members of the Institute enjoyed a wide variety of scientific lectures during the year, as indicated by the appended list of the 18 meetings held.

At a dinner preceding the stated meeting in November, the Institute received from the Department of Defense a Reserve Award Certificate in recognition of its outstanding record for cooperation with reservists and Reserve activities of the Armed Forces.

A symposium on "Earth Satellites as Research Vehicles" was held on April 18 as part of a program to promote the peaceful use of rockets. It brought together leaders in the fields of rocketry and upper air research for a discussion of the non-military applications of earth satellites.

In addition to these meetings that The Franklin Institute sponsored, its Lecture Hall and Franklin Hall were used by other scientific and cultural organizations for a total of a hundred meetings.

Institute Meetings During 1956.

Date	Subject	Speaker
*January 18	*Franklin and the Twentieth Century*	Dr. I. Bernard Cohen
†January 25	*Electrocardiography*	Dr. Ernest Frank
†February 1	*Danger, The Radio Spectrum is Bursting at the Seams*	Mr. Donald Fink
‡February 9	*The Relation of Membership to the Program of The Franklin Institute*	Dr. John S. Burlew
*February 15	*Nature and the Mind of Man*	Dr. W. F. G. Swann
†February 29	*Planning for Better Pictures*	Mr. Charles A. Kinsley
*March 21	*The Agricultural Situation Today*	Dr. W. L. Henning
†March 28	*General Electric Man-Made Diamonds*	Dr. Miles J. Martin
‡April 3	*Rocket to Mars*	Dr. I. M. Levitt
*April 18	*The Scientific Value of Artificial Satellites*	Dr. Fred L. Whipple
†May 2	*A New Twist*	Mr. Robert W. Neathery
*May 16	*High Energy Accelerators in the Atomic Energy Program*	Dr. Thomas H. Johnson
*October 17	*From Imbibition to Exhibition* Annual Medal Awards	Dr. Edwin H. Land
†October 31	*Scatter—A New Breakthrough in the Communications Bottleneck*	Dr. Harold A. Staras
†November 7	*The Air Defense Command—Its Mission, Organization and Operation*	Maj. Gen. N. B. Harbold
*November 21	*Radiation Damage—What Threat Does It Pose to Us and to Our Children* Philip C. Staples Lecture	Dr. Warren Weaver
‡December 5	*Airborne Prospectors*	Mr. Homer Jensen
*December 19	*The Atomic Nucleus and Modern Technology* Charles S. Redding Lecture	Dr. Gaylord P. Harnwell

* Stated Meeting of the Institute.
† Joint Meeting with Other Scientific Society.
‡ "Science is Fun" Meeting for Members.

A picture of the audience at the annual Medal Day meeting of The Franklin Institute, taken as part of the demonstration during the lecture by Dr. Edwin H. Land. The picture was taken with a Land Polaroid camera using a new emulsion that has such a high speed that artificial illumination was not required in the Lecture Hall. The original was prepared as a transparency and projected on the screen within a few minutes of the taking.

JOURNAL

The circulation of the JOURNAL increased from 4734 at the end of 1955 to 4876 at the end of 1956. The group of Associate Editors was increased during the year through eight new appointments to broaden coverage in the fields of electronics, mathematics, aerodynamics, thermodynamics, solid state physics, biophysics and nuclear engineering. Dr. William C. Meldrum, an Associate Editor since 1938, died late in December.

Commencing with the July issue, John S. Burlew succeeded Henry B. Allen as Editor, Mrs. Robert C. Glenn was designated as Managing Editor, and Henry B. Allen as Editor Emeritus.

The January issue of the JOURNAL was a commemorative one in recognition of the world-wide celebration of the 250th anniversary of the birth of Benjamin Franklin. This issue was devoted to papers submitted by distinguished representatives of 17 of the 22 scientific societies of which Franklin had been a member, to present a panoramic view of the past 250 years, which have witnessed almost the entire span of modern science.

Monograph No. 2 published in June under the auspices of the JOURNAL contains the full proceedings of the Institute-sponsored symposium on "Earth Satellites as Research Vehicles." By the end of 1956 the total distribution of this monograph was 570 copies.

COMMITTEE ON SCIENCE AND THE ARTS

The Franklin Medal for 1955 was awarded by the Institute on the recommendation of its Committee on Science and the Arts to Professor Arne Tiselius of the University of Uppsala, Sweden, in recognition of his investigations in the field of protein chemistry. The presentation was made at the annual meeting in January 1956 in order to highlight it as part of the celebration of the 250th anniversary of the birth of Franklin.

At the annual Medal Day on October 17, six medals were awarded.

Medals Awarded on October 17, 1956.

Medal	Recipient	Subject
Franklin	Frank Whittle	Jet engine development
Longstreth	Floyd A. Firestone	Ultra-sonic testing of metals
Potts	Edwin H. Land	One-step photographic process
Levy	Arthur W. Burks Robert McNaughton Carl H. Pollmar Don W. Warren Jesse B. Wright	Joint authorship of paper on "The Folded Tree" in July and August 1955 issues of the JOURNAL
Brown	Robert G. LeTourneau	Earth-moving equipment
Ballantine	Kenneth Bullington	Tropospheric wave propagation

Another award recommended during the year was the Newcomen Medal, to be awarded at the Franklin Birthday Dinner of the Newcomen Society on January 18, 1957.

The Committee held nine meetings during the year and its sub-committees held thirty-one meetings. Eight new members were appointed to the Committee and two members died, leaving a total of 69 at the end of the year.

1956 Medalists chatting with S. Wyman Rolph, Institute President.

Dr. John Frazer retired on July 31 after twenty years of devoted and distinguished service as Secretary to the Committee. Rear Admiral Delmer S. Fahrney, USN (Ret.), an aeronautical engineer who is well known as a pioneer in guided missiles, has been appointed as his successor, to take office on January 2, 1957.

STAFF

At the end of 1956 the staff of the Institute numbered 556, of whom 47 were stationed at the Bartol Research Foundation in Swarthmore, Pennsylvania. This was an increase of 20 persons during the year.

The practice of awarding service pins for ten years or more of continuous service on the staff of the Institute was resumed. Seven of the forty-three service pins awarded were for length of service greater than ten years.

Dr. Henry Butler Allen, who had been the operational head of the Institute since 1935, announced his retirement in January from the positions of Executive Vice President and Secretary. He was succeeded by Dr. John S. Burlew as Executive Vice President and by Mr. Hamilton Vaughan Bail as Secretary.

Other employees who retired during the year were Dr. John Frazer, who had been Secretary to the Committee on Science and the Arts since 1936, Mr. N. W. Sample, Jr., who had held various administrative positions since 1937, and Dr. Samuel Osbourn, a Library assistant since 1951.

Dr. William L. Fisher, well known as a lecturer to children in the Fels Planetarium and a member of the staff of the Planetarium since it opened in 1933, died in March. The death of Mr. Austin Nester, glassblower at the Bartol Research Foundation since 1925, occurred in October and that of Mr. G. Fred Herdel, supervisor of the reproduction unit in the Laboratories, occurred in November.

The life insurance and sick leave plans for employees were liberalized, effective the beginning of 1957.

PUBLIC RELATIONS

Most of the information about Franklin in support of the 250th Anniversary Celebration was handled through the public relations office of the Institute. The world-wide publicity given this event resulted in an increased appreciation of The Franklin Institute as well as of Franklin himself.

Commemorative postage stamp issued in honor of the 250th Anniversary of Franklin's birth, and first put on sale January 17 at a temporary post office on the ground floor of the Institute building.

Several events in connection with the 250th anniversary celebration took place at The Franklin Institute. A press party on January 4 was followed by a luncheon on Franklin's birthday (January 17), at which the City of Philadelphia's special Franklin Medal was presented to Mrs. Eleanor Roosevelt. The Institute's annual meeting that same evening was also arranged in honor of the Franklin anniversary, at which time the Franklin Commemorative Medal of the United States Congress was awarded to The Franklin Institute.

A new series of radio programs was produced by the Institute and presented on Sunday afternoon by radio station WRCV starting in June. The format of the program was a tour of the Museum and Laboratories through the eyes of a teenage boy and girl. The program was of a scientific, educational nature and is believed to be of greater public relations value than other media to reach the Institute's publics in order to tell the story of The Franklin Institute.

The Institute was the locale for a live telecast on the NBC network "Home Show" on the morning of October 22. Miss Arlene Francis and her staff appeared at five different spots in the Museum.

The weekly feature "Science, Servant of Man" was continued on the educational FM radio station WHYY and also was broadcast regularly over three independent Colorado radio stations.

The Institute was a co-sponsor of the celebration of International Museum Week in Philadelphia during October 7–14. Its public relations office served the Museum Council of Philadelphia in promoting the event through the press, radio, television, and outdoor advertising.

MEMBERSHIP

A further increase in membership amounting to 5 per cent occurred during 1956 so that at the end of the year the total of the different classes was 7459, compared with 7094 at the end of the preceding year.

Comparative Membership Figures.

	1956	1955
Honorary	35	35
Sustaining	15	15
Active	3361	3260
Associate	2702	2475
Student	620	496
Special Library	726	813
	7459	7094

A dinner honoring those persons who have been members for twenty-five years or longer was held on February 9, 1956. It was attended by 52 "Silver Members" and 252 others.

On two Sunday afternoons in February and March, special showings of scientific movies were held for members and their families.

Planting of Kwanzan cherry trees on Institute's lawn—a gift of the United Nations Association of Japan to the Institute, as part of the world-wide 250th celebration.

FINANCES AND GIFTS

The accounts of the Institute are audited each year by Messrs. Lybrand, Ross Bros. & Montgomery. Their report for 1956 will not be available until May 1957, at which time members may examine it in the office of the Treasurer. In the meantime preliminary figures are presented here covering financial results for the calendar year 1956.

The operations of the Laboratories in conducting sponsored research for industry and government are self-supporting, in that they not only meet all direct costs but also absorb their proportion of general Institute overhead. The gross revenue during 1956 amounted to $3,270,000, as already noted in an earlier section. It was sufficient to cover the cost of the new equipment needed for a further expansion of the work of the Laboratories.

The research at the Bartol Research Foundation cost $363,000. Of this total $246,000 was obtained from a group of government contracts, and $121,000 came from the income of the Bartol endowment funds, leaving a small surplus for the year.

The educational and general activities of the Institute are necessarily conducted at a loss. For instance, an admission fee to the Museum and Planetarium that would cover all costs would be prohibitively high. The total operating costs for the general activities—including the Museum and Planetarium, the Library, the JOURNAL, and the meetings—amounted to $551,000. Revenues from actual operations—including membership dues, admission fees, sponsored exhibits, and JOURNAL subscriptions—amounted to about half this amount, leaving a deficit of $263,000. This deficit was about the same as in 1955, even though the expenses had increased $23,000.

The income from endowment, which amounted to $111,000 (compared to $96,000 in 1955), was not nearly sufficient to meet this operating deficit. Some of it was offset by an appropriation from the Commonwealth of Pennsylvania amounting to $107,000 for the biennium 1955–1957, of which $57,000 was applicable to the calendar year 1956. Also the Board of Education, School System of Philadelphia, made an appropriation of $18,000 for two years in recognition of the contribution that The Franklin Institute makes toward visual education of school groups.

Some of the deficit was met in 1956 as in previous years through the generosity of private individuals, business firms, industry, and foundations. A group of donors, known as "Friends of Franklin," whose contributions help the Institute meet its annual operating costs, increased during 1956 from 380 to 442 and the contributions increased from $39,000 to $45,500.

The remainder of the deficit from the educational and general activities of the Institute (amounting to $30,000 in 1956) was met by the use of some of the surplus from the operations of the Laboratories.

An appropriation of $35,000 was received from the Commonwealth of Pennsylvania and one of $6,000 from the City of Philadelphia to defray expenses in connection with the celebration of the 250th anniversary of the birth of Benjamin Franklin.

A gift of securities valued at $5000 was received to endow a William B. Coleman Lecture Fund for a lecture every other year in the field of metallurgy.

Gifts totaling $4000 from three donors were added to the unrestricted endowment funds of the Institute.

Gifts amounting to $2,000 were received for special purposes, including laboratory equipment, Museum classroom equipment and the purchase of books and periodicals for the Library.

THE BIOCHEMICAL RESEARCH FOUNDATION

The Franklin Institute serves as trustee for the Biochemical Research Foundation, located at Newark, Delaware.

The study of inhibition of growth and metabolism of free cancer cells by means of modified sugars, separately and in combination, was continued. In other investigations sulfur-containing compounds, especially those of pyridine, were tested for cancer chemotherapeutic properties. Two parallel problems of the tumor-host type were studied: the first concerned the fate of the tumor in the hatched chick; the second constituted an attempt to establish appropriate tumor antigen-antibody tests for the verification of the presence of antibodies. The enzyme-longevity-diet-tumor investigations indicated that a definite correlation may exist between the occurrence and incidence of spontaneous tumors and the enzyme activity patterns. The growing of neoplastic cells *in vitro* received special attention after the acquisition of the chemostat and a search was begun for antimutagens.

Respectfully submitted,
By order of the Board of Managers,
S. WYMAN ROLPH
President

THE FRANKLIN INSTITUTE

MINUTES OF THE STATED MEETING

February 20, 1957

The Stated Monthly Meeting of The Franklin Institute was held on February 20, 1957, in the Lecture Hall. Mr. S. Wyman Rolph, President, called the meeting to order at 8:15 P.M. with approximately 400 members and guests in attendance.

The President stated that minutes of the Annual Meeting in January would appear in the February issue of the JOURNAL and will be submitted for approval at the next meeting.

After welcoming the Officers and Members of the Professional Group Chapters of the Institute of Radio Engineers and the Armed Forces Communications and Electronics Association, Mr. Rolph introduced General J. Harry LaBrum, Chairman of the joint meeting, who took the chair.

General LaBrum introduced the speakers of the evening, Brigadier General Stanley T. Wray, and Robert Bright, Jr. who spoke on the subject, "The SAGE System and its Implementation."

Their talks were enthusiastically received and were followed by an interesting question period.

The meeting adjourned at 9:45 P.M. with a rising vote of thanks to the speakers.

CECIL M. WATERBURY
Assistant Secretary

The Institute as seen across the Vine Street Throughway, under construction.

COMMITTEE ON SCIENCE AND THE ARTS

(Abstract of Proceedings of Stated Meeting held Wednesday, February 13, 1957.)

HALL OF THE COMMITTEE,
PHILADELPHIA, FEBRUARY 13, 1957.

MR. JOHN H. NEHER in the Chair.

The following report was presented for final action:

No. 3292: Work of J. B. Johnson in the Field of Noise Measurement.

This report recommended the award of an Edward Longstreth Medal to John Bertrand Johnson, of West Orange, New Jersey, "In consideration of his fundamental investigations leading to the recognition, measurement, and understanding of the thermal noise in resistors which forms the basis for the understanding of signal to noise ratio in electrical circuits and justly bears the name 'Johnson-Noise'."

DELMER S. FAHRNEY,
Secretary to Committee.

JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in this JOURNAL within the next few months:

WEAVER, WARREN: Radiations and the Genetic Threat

HARNWELL, GAYLORD P.: The Atomic Nucleus and Modern Technology

PENFIELD, R. H. AND H. ZATZKIS: Quantization of the Relativistic Harmonic Oscillator by Perturbative Methods with Application to Van der Waals Forces

HU, L. W.: Analysis of Die Profiles in Wire Drawing

BEKKER, M. G.: Latest Developments in Off-the-Road Locomotion

GREENSPAN, DONALD: On a "Best" 9-Point Difference Equation Analogue of Laplace's Equation

SWANN, W. F. G.: Reality, Imagery and Fantasy

POWER, G. AND D. L. SCOTT-HUTTON: Slow Shearing Motion over a Hollow

KUMAR, SUDHIR AND NORMAN DAVIDS: Multiple Scabbing in Materials

KLEIN, BERTRAM: Shear Buckling of Simply Supported Rectangular Plates Tapered in Thickness

LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the Library. Duplicates received will be transferred to other libraries as gifts of the donor. 287 items have been added the past month.

Photostat service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open from 9 A.M. until 5 P.M. on Mondays, Tuesdays, Thursdays, Fridays and Saturdays; and 2 P.M. until 10 P.M. on Wednesdays.

RECENT ADDITIONS

ARCHITECTURE AND BUILDING

JORDON, RICHARD C. AND PRIESTER, GAYLE B. Refrigeration and Air Conditioning. Ed. 2. 1956.

TIMBER ENGINEERING COMPANY. Timber Design and Construction Handbook. 1956.

ASTRONOMY

SIEGEL, CARL LUDWIG. Vorlesungen über Himmelsmechanik. 1956.

ATOMIC ENERGY

COMMITTEE FOR COMPILATION OF REPORT ON RESEARCH IN THE EFFECTS OF RADIOACTIVITY. Research in the Effects and Influences of the Nuclear Bomb Test Explosions. 1956.

THE PANEL ON THE IMPACT OF THE PEACEFUL USES OF ATOMIC ENERGY. Peaceful Uses of Atomic Energy—Report of the Panel. Vol. 1–2. 1956.

BIOGRAPHY

LESSING, LAWRENCE. Man of High Fidelity: Edwin Howard Armstrong. 1956.

BIOLOGICAL CHEMISTRY

CONFERENCE ON BIOLOGICAL WASTE TREATMENT, MANHATTAN COLLEGE. Biological Treatment of Sewage and Industrial Waste; Papers. 1956.

THIERS, HENRI. Les Vitamines; Biochimie; Biologie, Emploi Thérapeutique. 1956.

CHEMISTRY AND CHEMICAL TECHNOLOGY

GRINBERG, A. A. Einführung in die Chemie der Komplexverbindungen. 1955.

HUR, J. JAMES, ED. Chemical Process Economics in Practice. 1956.

LIEBIG, JUSTUS. Lettres Sur la Chimie. 1847.

LIEBIG, JUSTUS. Nouvelles Lettres Sur la Chimie. 1852.

MICHEEL, FRITZ KARL HERMAN AND KLEMER, ALMUTH. Chemie der Zucker und Polysaccharide. Ed. 2. 1956.

SMIRNOW, SEVGEI SERGEEVICH. Die Oxydationszone Sulfidischer Lagerstätten. 1954.

CIVIL ENGINEERING

ABBETT, ROBERT W., ED. American Civil Engineering Practice. Vol. 1–2. 1956.

DICTIONARIES

HEFLIN, WOODFORD AGEE, ED. The United States Air Force Dictionary. n.d.

ELECTRICITY AND ELECTRICAL ENGINEERING

INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION. Reference Data for Radio Engineers. Ed. 4. 1956.

SPREADBURY, F. G. Electronic Measurements and Measuring Instruments. 1956.

ENGINEERING

CAMPUS, F. AND MASSONNET, C. Recherches sur le Flambement de Colonnes en Acier A 37, á Profil en Double té, Sollicitées Obliquement. n.d.

GENERAL

HUGH-JONES, E. M., ED. The Push-Button World; Automation Today. 1956.

MEIER, RICHARD L. Science and Economic Development: New Patterns of Living. 1956.

PALMER, ARTHUR JUDSON. Riding High; the Story of the Bicycle. 1956.

GEOLOGY

SAWARIZKI, A. N. Einführung in die Petrochemie der Eruptivgesteine. 1954.

GRAPHIC ARTS

PUSHKOW, W. W. AND NOTKING, N. M. Fotomechanische Prozesse in der Chemigrafie. 1955.

HISTORY

HUDSON, DEREK AND LUCKHURST, KENNETH W. The Royal Society of Arts, 1754–1954. 1954.

HOROLOGY

VULLIAMY, BENJAMIN LEWIS. A Portion of the Papers Relating to the Great Clock for the New Palace at Westminster. 1848.

MANUFACTURE

PREIS, G. A. Schnellzerspanung von Metallen. 1953.

MATHEMATICS

AUMANN, GEORG. Reele Funktionen. 1954.
BIEBERBACH, LUDWIG. Einführung in die Theorie der Differentialgleichungen im Reellen Gebiet. 1956.
BLASCHKE, WILHELM. Einführung in die Differentialgeometrie. 1950.
CONFORTO, FABIO. Abelsche Funktionen und Algebraische Geometrie. 1956.
LASS, HARRY. Elements of Pure and Applied Mathematics. 1957.
MAAK, WILHELM. Fastperiodische Functionen. 1950.
OBERHETTINGER, FRITZ AND MAGNUS, WILHELM. Anwendung der Elliptischen Funktionen in Physik und Technik. 1949.
SAUER, ROBERT. Anfangswertprobleme bei Partiellen Differentialgleichungen. 1952.
SAXER, WALTER. Versicherungsmathematik. Pt. 1. 1955.
SCHULER, MAXMILIAN JOSET JOHANNES EDUARD. Einführung in die Theorie der Selbsttätigen Regler. 1956.
SPECHT, WILHELM. Gruppentheorie. 1956.
TOEPLITZ, OTTO. Die Entwicklung der Infinitesimalrechung. Vol. 1. 1949.
WAERDEN, VAN DER. Algebra. Ed. 4. Pt. 1. 1955.

MECHANICAL ENGINEERING

LUFT, HANS. Maschinenelemente. Ed. 6. 1955.

METALLURGY

HAYWOOD, F. W. AND WOOD, A. A. R. Metallurgical Analysis. Ed. 2. 1957.

PHOTOGRAPHY

BAIER, WOLFGANG. Optik, Perspektive und Rechnungen in der Fotografie. 1955.

PHYSICS

CZWALINA, ARTHUR. Die Mechanik des Schwimmenden Körpers. 1956.
EMELÉUS, KARL GEORGE. The Conduction of Electricity through Gases. Ed. 3. 1951.
EMERSON, WILLIAM. Tracts Containing Mechanics or the Doctrine of Motion. 1793.
FINKELBURG, KARL ERNST WOLFGANG. Einführung in die Atom-Physik. Ed. 4. 1956.
HANNAH, JOHN AND STEPHENS, RICHARD COURTNEY. Examples in Mechanical Vibrations. 1956.
KRBEK, FRANZ VON. Grundzüge der Mechanik. 1954.
KOCKEL, BERNHARD. Darstellungstheoretische Behandlung Einfacher Wellenmechanischer Probleme. 1955.
PORTER, ALFRED WILLIAM. Thermodynamics. Ed. 4. 1951.
VARIGNON, PIERRE. Projet d'une Nouvelle Mechanique. 1687.
WEIZEL, WALTER. Lehrbuch der Theoretischen Physik. Ed. 2. Vol. 1. 1955.

RADIO

DREW, CHARLES E. How to Pass Radio License Examinations. Ed. 3. 1952.

RAILROADS

AHRONS, E. L. The Development of British Locomotive Design. 1914.

SUGAR

LIPPMANN, EDMUND O. VON. Geschichte der Ruebe (Beta) als Kulturpflanze. 1925.
PAYEN, A.; GAUTIER ET AL. Résumé du Cours Pratique de Fabrication du Sucre Indigene. 1838.

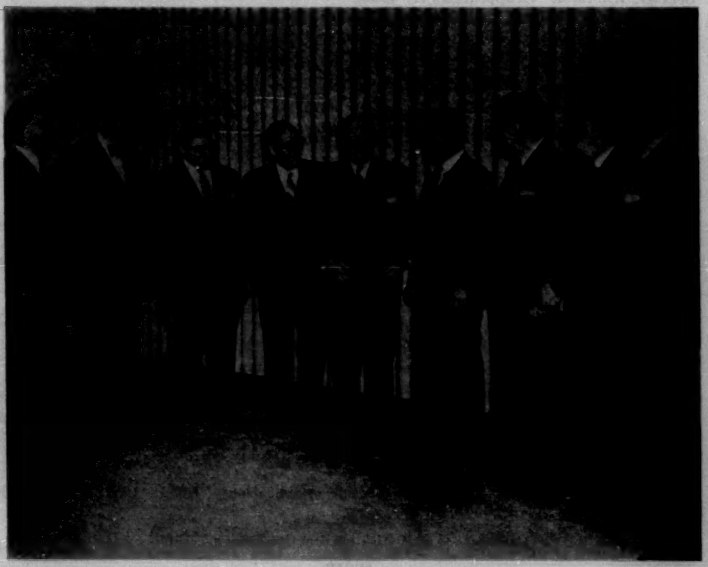
MEMBERSHIP

On February 14, 1957, the Institute paid tribute to thirteen men who had completed 25 years of consecutive membership during 1956. Seven of the new Silver Members were able to attend the reception and dinner in their honor. As souvenirs of the occasion, the new Silver Members received trays—gift of the Doehler-Jarvis Division of the National Lead Co.—and initialled paper weights containing 1956 quarters.

Following dinner, Morton Gibbons-Neff, Chairman of the Membership Committee, introduced the seven new Silver Members present: Abraham D. Caesar; Daniel B. Curll, Jr.; Edward Dawson; J. Bennett Hill; Penrose R. Hoopes; William Melas; and Julius F. Neumueller. He also recognized the following Silver Members of previous years who were present: J. D. Shattuck (1910); Howard S. Worrell (1912); Franklin P. McConnell (1913); Frank H. Sauer (1916); Walter J. Lehman (1930); and "myself" (1930).

The dinner guests then heard Dr. John W. Mauchly, Director of the Eckert-Mauchly Division of Remington Rand, describe—and watched him demonstrate—his newest "computer," in an enlightening talk entitled "Computing Is Fun." The computer, constructed of plywood, operated with fifty-cent pieces.

With Dr. Mauchly's explanation of computing machines fresh in their minds, the audience of about 200 toured the UNIVAC installation and the new Computation Exhibit sponsored by Remington Rand. The tour included a movie, "Numbers Are Our Business," in which the history of man's attempt to count and measure things was portrayed.



The Silver Members of 1956 who were present at the February 14 dinner, with the President of the Institute and the Chairman of the Membership Committee. Left to right: Edward Dawson, William Melas, Abraham D. Caesar, Morton Gibbons-Neff, S. Wyman Rolph, Daniel B. Curll, Jr., Penrose R. Hoopes, J. Bennett Hill and Julius F. Neumueller.

SHORT BIOGRAPHICAL NOTES ON THE 1956 SILVER MEMBERS

CARL BREER—Retired Director of Engineering for the Chrysler Corporation. He is credited with being the co-designer of the first Chrysler-built car.

ABRAHAM D. CAESAR—Patent Attorney with Caesar & Rivise. He is co-author (with his partner) of "Patentability and Validity" and "Interference Law and Practice."

DANIEL B. CURLL, JR.—President and Director of Chemical Enterprises, Inc., and a Consultant in the fields of Chemical Engineering, Metallurgy and Long Term Planning.

EDWARD DAWSON—Mechanical Engineering Department of The Pennsylvania State University. He teaches engineering, but continues his research and development work in mechanical engineering.

J. BENNETT HILL—Director of the Research and Development Department of Sun Oil Co. He holds twelve patents in the coal-tar and petroleum fields.

PENROSE R. HOOPES—Consulting Mechanical Engineer. He specializes in automatic machines for the production of hardware, clocks, paper and rubber goods.

FREDERICK C. HOLTZ—Member of the Board of Directors of Sangamo Electric Co. He was instrumental in the formation of the first signal unit at Fort Benning.

WILLIAM MELAS—Consulting Engineer to the industrial instruments manufacturing industry. He holds eight patents, and several are pending, in this field.

PARRY MOON—Professor in the Electrical Engineering Department of Massachusetts Institute of Technology. He is well known for his many papers on lighting design and illumination.

JULIUS F. NEUMUELLER—Professor Emeritus of Physiological Optomtery, Pennsylvania State College of Optometry. He is the recipient of a gold medal for distinguished service to Optometry.

LAURENCE P. SHARPLES—Vice President of Sharples Corporation. Interested in aviation, he is Chairman of the Board of Aircraft Owners and Pilots Association.

WILLIS R. WHITNEY—Honorary Vice President of the General Electric Research Laboratories. He received the Franklin Medal in 1931 in recognition of his research and professional leadership.

CHARLES E. BERGER—We regret that information on Dr. Berger was not available in time to be included in this JOURNAL.

ACTIVE MEMBERS ELECTED BY THE BOARD OF MANAGERS

February 20, 1957

ACTIVE FAMILY

Charles J. Geyer, Jr.	Samuel Mackler	Frederick W. Schwarz
William H. James	William Francis O'Shea	Thomas D. Sharples
Hubert Kahanna	Frank W. Panepinto	M. F. Van Istendal, Jr.

ACTIVE

Paul E. Atkinson	Joseph Eger	Joseph L. Ramsay
Rowland N. Brauch	Eric W. Ericson	William Otto Weber
Anthony R. Catrambone	Carl E. Gryotko	Roy F. Weston
Alfred F. Degerberg	Irving G. Klaus	Frank M. Woehl
Herbert E. Doerr	Frederick F. Ohntrup	Alfred J. Zimmerman
	Thomas M. Patterson	

ACTIVE NON-RESIDENT

W. Wayne Glover

William Klein, Jr.

NECROLOGY

Anthony J. Abraham '48	Charles Lakatos '53	Thomas B. K. Ringe '45
Edgar W. Baird, Jr. '36	S. DeW. Ludlum '54	J. M. Traugott '53
Walter Bowers '46	William B. Meldrum '38	William H. Wanamaker, Jr. '36
R. N. Davis '43	Augustine F. S. Musante '39	Theodore R. Yoos '49

The following are Silver Members, having belonged continuously for twenty-five years or more. The dates are years of election to membership.

1908
W. M. C. Kimber

1909
Theobald F. Clark
Walton Clark, Jr.
James McGowan, Jr.
T. Edward Ross

1910
Richard B. Brown
Joseph S. Hepburn
Joseph W. Lippincott
J. D. Shattuck
J. M. Weiss

1911
Seth B. Capp
W. H. Fulweiler
Charles Penrose

1912
James Barnes
Morris Llewellyn Cooke
Edwin Elliot
Walter Palmer
Julian S. Simsohn
Howard S. Worrell

1913
Edward Bartow
Sterling H. Bunnell
Irenee duPont
S. B. Eckert
Ralph E. Flanders
N. E. Funk
Lionel F. Levy
E. Mallinckrodt, Jr.
Frank M. Masters
Franklin P. McConnell
William Maul Measey
W. Chattin Wetherill
D. Robert Yarnall

1914
Russell L. Brinton
George S. Crampton
Ernest L. Huff
K. G. Mackenzie
George Wharton Pepper

1915
Thomas D. Cope
John C. Cornelius, Jr.
H. Jermain Creighton
Thomas W. Elkinton
Richard Howson
W. Wallace McKaig

1916
Henry B. Allen
James G. Detwiler
Zay Jeffries
Thorsten Y. Olsen
Frank H. Sauer
B. E. Shackelford
Arthur Synnestvedt
Charles N. Weyl

1917
A. D. Chambers
Francis J. Chesterman
Walter S. Crowell
William J. Fitzmaurice, Jr.
Rolfe E. Glover, Jr.
Harold Goodwin, Jr.
Arthur W. Lowe
Frank S. MacGregor
Francis F. Milne, Jr.
C. H. Quinn
Sylvan D. Rolle
Robert L. Wood
Henry Woodhouse

1918
Charles H. Colvin
Walter O. Snelling

1919
Charles E. Brinley
Henry Colvin, 2nd
E. A. Eckhardt
George W. Furness
Frank H. Griffin
Hiram S. Lukens
H. Conrad Meyer
J. Howard Pew
Edmund G. Robinson
L. K. Sillcox
W. Leigh Smith
John Sealy Townsend

1920
Robert Cameron Colwell
Chester Lichtenberg
P. S. Lyon
Haviland H. Platt
Carl D. Pratt

1921
Roland L. Andreau
Leonard T. Beale
J. Ed. Brewer
Arthur L. Day
Frederic Palmer, Jr.
Howard Stoertz
James Stokley
Edward R. Weidlein
S. Weinberg

1922
C. Douglas Galloway
Joseph F. Greene
C. E. K. Mees

1923
Henry Clay Gibson
Howard S. Levy
William C. Melcher, Jr.
John F. Metten
Jessie A. Rodman
Richard G. Sagebeer
Coleman Sellers, 3rd
H. Birchard Taylor
Francis B. Vogdes
Joseph J. Vogdes

1924
Peter Abrams
H. Carl Albrecht
Clement Starr Brinton
Lee Davidheiser
William G. Ellis
T. R. Harrison
Valentine Hiergesell
Karl F. Oerlein
Edward B. Patterson
Harold Pender
Nicholas G. Roosevelt
Alfred O. Tate
Walter C. Wagner
James Lloyd Weatherwax

1924 (cont.)
Alexander Wilson, 3rd
William Zimmermann

1925
Jack G. Binswanger
Marion Eppley
John Graham Foley
J. V. Giesler
C. R. Kraus
J. Kenneth W. Macalpine
H. F. Porter
W. F. G. Swann

1926
Charles B. Bazzoni
Neils Bohr
O. E. Buckley
William Findlay Downs
Henry C. Evans
Edward L. Forstall
Lewis H. Hendrixson
Charles S. Leopold
Alfred L. Loomis
J. H. Manning
William Clarke Mason
Clement B. Newbold
O. M. Patton
Charles S. Redding
Dexter N. Shaw
Sydney L. Wright
Charles S. Wurts, Jr.

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William Adam
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William DeKrafft
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Julius Neumueller
Laurence P. Sharples
Willis R. Whitney

The following are Gold Card Members, having belonged continuously for fifty years or more:

Alexander Sellers 84
Fred H. Colvin 88
G. H. Clamer 91
J. H. Granberry 95
Edward Woolman 95
E. A. Muller 99
James M. Caird 01
Kern Dodge 02
John P. B. Sinkler 02
Charles H. Howson 03
Frank S. Busser 04
C. Mahlon Kline 04
George R. Hall 05
Darthela Clark 07
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THE BIOCHEMICAL RESEARCH FOUNDATION

ELLICE McDONALD, FOUNDER
WILLIAM G. BATT, DIRECTOR

***Abstract of* Alkaline Phosphatase Activity and Diet.**—MORRIS H. ROSS AND WILLIAM G. BATT (*The Journal of Nutrition*, **60**, 137–144 (1956)). Alkaline phosphatase activity of rat liver was found to be sensitive to variation in the proportion of casein and dextrose in the diet. Activity values were found to be high not only when there was a large proportion of dextrose but also when there was a large proportion of casein in the diet. Low activity values were found when these dietary constituents were present in approximately equal proportions. Alkaline phosphatase activity was found to be directly affected by variation in the casein content when the dextrose content was held constant and by variation in the dextrose content when the casein content was held constant. A variation in the amount or in the proportion of the dietary factors, casein and dextrose, was shown to alter the alkaline phosphatase activity.

THE FRANKLIN INSTITUTE LABORATORIES
FOR RESEARCH AND DEVELOPMENT
NICOL H. SMITH, DIRECTOR

DETERMINATION OF THE ORIENTATION OF CRYSTALLITES IN ELONGATED PARTICLES IN THE SINGLE-DOMAIN RANGE *

BY

ROBERT B. CAMPBELL

ABSTRACT

A method has been developed by the staff of the Solid State Physics Division for determining the orientation of crystallites in a multi-crystalline, acicular particle by electron diffraction techniques. In a particle with oriented crystallites, all of the crystallites have a common crystallographic direction along the axis of the particle; the crystallites may be rotated randomly about the common direction. Utilizing the selected area diffraction unit of the RCA-EMU-2C electron microscope, a single particle can be isolated and its diffraction pattern obtained. At the same time, the spatial orientation of the particle with respect to the pattern is determined.

If the particle being studied is multi-crystalline with oriented crystallites, the diffraction pattern has the appearance of an X-ray rotation diffraction pattern of a single crystal; that is, a very definite pattern of well defined spots. If, however, the crystallites are not oriented, the pattern has the usual appearance with arcs or circles. Interpreting the oriented pattern by fairly standard methods, one can show which common crystallographic direction of the crystallites is along the axis of the particle.

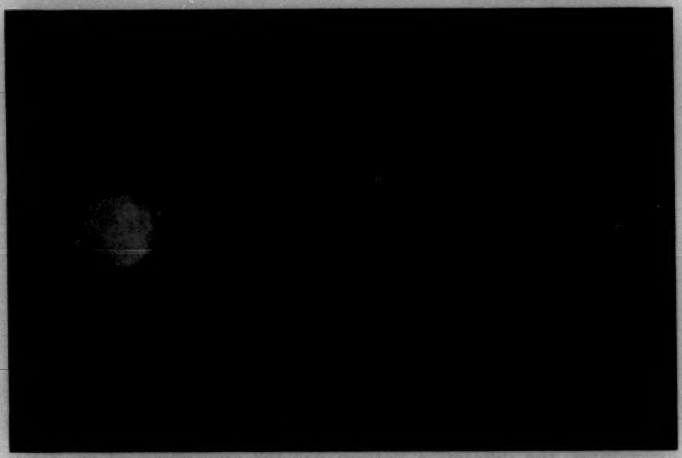
Initial experiments were carried out on samples of γ-Fe_2O_3 with a particle size of approximately $1\mu \times 0.2\mu$ and with crystallite sizes ranging from 50 Å to 800 Å as determined by X-ray line broadening.

In general, the data indicate that a large majority of the particles have oriented crystallites. This orientation direction varies from particle to particle, but within a given particle all the crystallites usually have a common orientation axis. The crystallographic direction found is generally of low order such as 210, 221, etc. Particles have been observed in which the orientation is not perfect, with the spots being slightly elongated, and a few particles observed have shown

* This work was carried out under the cooperatively sponsored Magnetics Research Program at The Franklin Institute Laboratories for Research and Development. This is an abstract of a paper that has been submitted to the *Journal of Applied Physics*.

essentially random orientation. The results may be compared with those of Osmond (1) who by an entirely different method placed the <111> direction along the axis of the particle.

Similar work on iron oxide hydrates and pure iron is now being carried out.



At left is the selected area diffraction pattern of the iron oxide particle on the right. The pattern shows how the crystallites in the particle are oriented.

REFERENCE

(1) W. P. Osmond, *Proc. Phys. Soc.*, Vol. 66, 4-B, pp. 265 (1953).

BOOK REVIEWS

HOMOLOGICAL ALGEBRA, by Henri Cartan and Samuel Eilenberg. 390 pages, 6 × 9 in. Princeton, Princeton University Press, 1956. Price, $7.50.

The homology concept—one of Poincaré's most fruitful creations—is a device by which some of the most primitive properties of spaces can be measured and analyzed. The basic relation on which homology rests is that of *bounding*. Let X_n denote an n-dimensional geometric configuration. The boundary of X_n, denoted by dX_n is a configuration of dimension $n-1$. For example, if X_3 is a solid portion of ordinary 3-dimensional space, dX_3 is a closed surface (therefore 2-dimensional) and if X_2 is a piece of surface, dX_2 is a closed curve (therefore 1-dimensional). Of course if X_2 is a closed surface, it has no boundary. In particular, if $X_2 = dX_3$, then $dX_2 = 0$ which can be written $ddX_3 = 0$. In fact the relation $ddX = 0$ holds no matter what the dimension of X. Two configurations X and Y can be combined into a single one by a process of addition and if definitions are suitably made, the boundary of the sum is the sum of the boundaries. Thus the totality of configuration is a given space in an additive group C in which d is a linear operator which reduces dimensions by one unit and satisfies the condition $dd = 0$. Those elements of C which are of the form dX constitute a subgroup B and those elements X for which $dX = 0$ form a subgroup Z. It follows from the relation $dd = 0$ that B is, in fact, a subgroup of Z and consequently we can form the quotient group $H = Z/B$. This is the homology group of the space in which the configurations lie; it has been known for half a century and is a basic tool in the topology of spaces.

One can of course think of $\{C, d\}$ as a purely algebraic system. A remarkable discovery in recent years is that such systems arise in a natural way, not only in geometry but also in algebra. Consider an abstract group G, for example. It is possible in a natural manner to "realize" G as a group of transformations of a space S into itself such that no transformation except the identity leaves any point fixed. Moreover, S can be so chosen that its homology group is trivial. A new space S' can now be formed from S by identifying two points whenever one is the image of the other under a transformation of the group. The boundary group of S', depends only on the group G which is under analysis and is in general non-trivial. Thus we have associated with G an abelian group $H(G)$. This is an important invariant of the group G and provides a new tool for analyzing its properties. Other algebraic structures, notably Lie algebras and associative algebras, also admit homology invariants. The discovery of these invariants has opened a new algebraic field the foundations of which are solidly laid in the present work. The known homology theories of various structures are brought under a single unified theory based on a host of new concepts. This theory sheds new light on classical results and is of such generality as to be applicable to many situations not covered by the special cases considered up to the present.

The book is self-contained and presupposes very little knowledge of mathematics. The development proceeds in textbook fashion and each chapter ends with a generous set of exercises. It would, however, be a mistake to dismiss this work simply as a text. It is on the contrary a technical scientific achievement of the first magnitude. Both authors are recognized masters and each has been heavily involved in the development of the subject. A work as original and powerful as this will certainly change the aspect of algebra and may well stimulate currents of mathematical development which will soon make parts of the book itself seem out-of-date. In any case the basic concepts are so carefully constructed that they will rapidly become standard algebraic tools.

P. A. SMITH
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RHEOLOGY. THEORY AND APPLICATIONS. VOLUME 1, edited by Frederick R. Eirich. 761 pages, diagrams, 6 × 9 in. New York, Academic Press, Inc., 1956. Price, $20.00.

This volume is another of the publications becoming so popular of late, wherein an editor has solicited contributions from a number of experts. The use of different collaborators necessarily introduces difficulties in the uniform presentation of the subject, especially in fields lacking a standard nomenclature—a situation which prevails in the field of rheology. The necessity for such a standard nomenclature is evident in the present work, in which there are almost as many systems of nomenclature as there are authors. Even uniformity of such a symbol as η for viscosity could not be achieved.

Another fault stemming from the variety of contributors is that of repetition—some subjects being mentioned four or five times. As examples, the tensor treatment of elastic phenomenon has been described five times by different contributors, and the dashpot and spring models for the description of viscoelastic phenomenon were used at least three times.

A third very marked peculiarity is the contributors' complete disregard of their colleagues. The omission of cross referencing between articles in the volume itself is understandable; however, it is difficult to understand why most of the theoretical contributors only reported their own work, disregarding developments in the same field by other investigators. Even in such a subject as the viscosity of macromolecules, the work of Debye and Bueche has been nearly completely overlooked, as has Rouse's theory. In the theoretical part, the contributions of Eisenschitz have not even been mentioned in the index. No attempt has been made to correlate the work, for example, of Debye and Bueche with that of Kirkwood and Riseman, although it is well known that they give the same results. On the other hand, in their separate treatments of tensor theory in rheology, Reiner and Rivlin obtain different results, serving to confuse the reader.

Before discussing each article briefly, we may note that most of them are republications of the authors' previous works—although this in itself need not be a drawback in a "source book."

The article by M. Reiner, "Phenomenological Macrorheology," treats the theoretical aspects of rheology. "Finite Plastic Deformation," by W. Prager, covers in a lucid way the mathematics of the Bingham body. D. C. Drucker, in "Stress-Strain Relations in the Plastic Range of Metals—Experiments and Basic Concepts," describes the plasticity of metals. Two articles—one by G. J. Dienes, "Mechanical Properties and Imperfections in Crystals," and one by J. M. Burgers and W. G. Burgers, "Dislocations in Crystal Lattices"—treat the rheological properties of crystals in detail. J. Fleeman and G. J. Dienes, in "Mechanical Properties of Metals," describe the mechanical properties of metals, especially in the plastic range. R. B. Dow's contribution, "Some Rheological Properties Under High Pressure," gives a complete description, possibly for the first time, of the rheological properties of materials under high pressures, with a description of experimental results together with the instrumentation. A. Bondi discusses the theory of viscosity of pure liquids in "Theories of Viscosity." The article by R. S. Rivlin, "Large Elastic Deformations," provides an up-to-date summary of the theories he has published during the last ten years. T. Alfrey and E. F. Gurnee, in their paper on "Dynamics of Viscoelastic Behavior," discuss the viscoelastic properties of materials with special reference to theories involving vibrations.

One of the most valuable articles in the volume is the one on "Viscosity Relationships for Polymers in Bulk and in Concentrated Solution," by T. G. Fox, S. Gratch and S. Loshaek, who give, for the first time, a complete and up-to-date description of the properties of bulk polymers. J. Riseman and J. G. Kirkwood summarize previous theoretical work by Professor Kirkwood in the field of viscosity and viscoelasticity, in "The Statistical Mechanical Theory of Irreversible Processes in Solutions of Macromolecules." "The Viscosity of Colloidal Suspensions and Macromolecular Solutions," by H. L. Frisch and R. Simha, is a summary of the work of the senior author in this field during the last

twenty years. The problem of streaming and stress birefringence is considered in a competently written survey by A. Peterlin entitled "Streaming and Stress Birefringence." J. G. Oldroyd summarizes—probably for the first time—his work in the field of viscoelasticity, in his "Non-Newtonian Flow of Liquids and Solids." "Acoustics and the Liquid State," by R. B. Lindsay, covers experimental results in the field of acoustics in the liquid state.

In the Appendix the Editor reviews the Weissenberg theory. Unfortunately, some of the main points of the theory have not been mentioned, such as: the differential equation involving the time derivatives of both stress and strain published in 1930 by Weissenberg; the reference to the normal stresses in flow; the Weissenberg effect; and the importance of the recoverable strain for the description of viscoelastic phenomenon.

This first volume is essentially the theoretical part of a proposed three-volume set. It may well be that the theoretical detachment from experimental results, so evident in this first volume, will be complemented by data in the other two volumes; however, the fact that the authors have disregarded parallel results and experimental data in their own fields is such a serious drawback that the application of their theories is made difficult.

The book represents the individual opinions of its many contributors and so leaves to the reader the decision as to which theory is more applicable to each particular problem. The main asset of the book—which was intended to be a "source book of rheology"—is that it allows workers in the field to acquaint themselves, in a single book, with the views of different investigators. In that respect, one could recommend the book for research laboratories engaged in rheological work.

It must be stated here that a book of a similar nature, edited by J. J. Hermans, "Flow Properties of Dispersed Systems" (1953), eliminates some of the faults mentioned above by subdividing the field into larger divisions, thereby eliminating the duplication of effort that is especially apparent in the book under discussion.

WLADIMIR PHILIPPOFF
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THE MILKY WAY, by Bart J. Bok and Priscilla F. Bok. Third edition, 269 pages, 6½ × 9½ in. Cambridge, Harvard University Press, 1957. Price, $5.50.

Fantastic advances have been achieved in all the sciences. Development after development cascades through the corridors of time and today the impressive panorama of science is a tribute to the ingenuity of man. These achievements are not restricted to the "practical" sciences. Even those of an exotic nature have seen stimulating advances. One of these more exotic sciences is astronomy and one of the most important facets of astronomy is the study of the Milky Way or our Galaxy of which the sun is a member.

To delineate the details of this vast system of stars takes an expert with a speculative turn of mind. Such experts are Bart J. Bok and his charming wife Priscilla. Together in 1941, they authored the first edition of *The Milky Way* as one of the "Harvard Books on Astronomy."

Now the third edition is presented, but it is a misnomer, for it is a completely revised third edition. The revisions in this edition make the other two editions completely obsolete.

Since 1941 a tremendous volume of astronomical research has been pursued all over the world. New methods and new techniques have been applied to the study of the Milky Way. New results have been amassed by various investigators working with different instruments. Until the publication of this book this material was available only in widely scattered sources and many of these were in languages not easily translated. Now the Boks have collated all this new material and incorporated it into their new book.

As an example of this service, they have included the work of the Russian astronomer, Ambartsumian, on "Star Associations and Aggregates." The pioneering Russian work on faint emission nebulosities is described.

Dr. Bok, an indefatigible worker, has become intimately associated with the radio exploration of the Milky Way. This new and powerful probe is destined to reveal significant information about our system. In this book is found a complete survey of this field as it is known today. This is the best

exposition of radio astronomy that this reviewer has ever seen.

The book contains many photographs which skillfully complement the text and the style of writing is excellent. In all, the Boks have produced the best possible book on the Milky Way and it is destined to be the standard for many years.

I. M. LEVITT
Fels Planetarium

PHASE DIAGRAMS IN METALLURGY, by Frederick N. Rhines. 340 pages, illustrations, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1956. Price, $12.00.

The metallurgist is confronted by problems in his daily work that call upon his knowledge of phase equilibria for their solution. He utilizes equilibrium diagrams to express the comples relations that exist between phases in alloy systems. The binary systems are relatively easy to interpret; however, the more complex alloys are much more difficult. A comprehensive, readable text has been needed for many years to aid the metallurgist in understanding and becoming thoroughly familiar with this necessary subject. It has been two decades since a text devoted to phase diagrams has been published; thus, the present text fills the requirements that the subject is of appreciable interest and there is no other up-to-date book concerning it.

As one might gather from the title, the emphasis is placed on metal systems. All of the examples given are for metals, and interpretation is made in metallurgical terms. The author relates the phase diagrams to many aspects of physical metallurgy. The reader is taken in a straightforward manner from the simple to the complex. He progresses from unary systems through binary, ternary, and quaternary systems. Many of the readers will recognize Dr. Rhine's now famous lecture notes in chapters 2 to 18. These notes have enjoyed a very widespread circulation and have been used by graduate and undergraduate students of many schools and countries.

By the time the reader has covered the binary systems, he should be well grounded in the principles and application of the Gibbs' phase rule. He is instructed in all of the possible combinations of simple systems such as the eutectic, eutectoid, peritectic, monotectic, etc. The author points out how errors can be spotted on phase diagrams by simple applications of known principles.

The three and four component systems are profusely illustrated by space diagrams and exploded models of the phase diagrams. These are extremely well chosen and carefully done and should be of great help toward understanding the phase relationships involved.

Over fifty pages are devoted to systems with more than three components. Although this is brief for such a difficult subject, it is very instructive and is more complete than any other treatment of the subject thus far.

The author includes problems at the end of the chapters. Included in the appendices are a table of atomic weight and very complete instructions by C. S. Smith for the interconversion of volume, weight, and atomic percentages. There are a temperature conversion table and a subject index.

R. L. SMITH
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CHEMICAL ENGINEERING PRACTICE. VOLUME I: GENERAL, edited by Herbert W. Cremer and Trefor Davies. 508 pages, diagrams, 6 × 9¼ in. New York, Academic Press, Inc.; London, Butterworths Scientific Publications; 1956. Price: $17.50 (non-subscription); $13.30 (subscription, valid on orders for complete set of 12).

The editors have embarked on a monumental task of describing an expanding quantity-chemical engineering practice—in considerable detail for readers with widely different backgrounds. They introduce their series with a history of the development of chemical engineering and a philosophical discussion of the role of the chemical engineer.

The economics of production includes a study of the growth of manufacturing, trade and labor organizations and their effect on the industries. This volume covering general aspects of the subject would be incomplete without this section although the specific information is limited in application to England's economy.

Materials balances are presented in adequate fashion with a liberal use of examples. The chapter on preparation of energy balances fortunately includes most of the basic

derivations of the thermodynamic quantities directly. At times it suffers from an interchange of symbols which require translation.

Interpretations of the functions of pilot plants and semicommercial units have the advantages of the industrial viewpoint. Suggestions on organization and operation and integration of these activities within a company reflect the many years of experience of the authors with difficulties which may be encountered in operating pilot plants while several other divisions of a company are clamoring for results and products.

Flow diagrams, the basis for comprehensive discussions of a development, are given commendable treatment with numerous examples. The tables of symbols will serve the graduate as well as the beginner to maintain standards of expression. The final chapter on units, dimensions and calculations is essential for reference to conversions from one system to another.

In general, the editors have fulfilled their intentions of treating a many-faceted subject in a manner that should be interesting and useful to the theoretical worker, administrator and practicing engineer. While this is the first of a series of twelve volumes, it will stand on its own merits for an introduction to the subject and serve as a ready reference in addition to stimulating further study through its bibliographies.

R. S. DALTER
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SOLAR ECLIPSES AND THE IONOSPHERE, edited by W. J. G. Beynon and G. M. Brown. 330 pages, diagrams, $7\frac{1}{4} \times 9\frac{3}{4}$ in. London and New York, Pergamon Press, 1956. Price, $21.00.

This is 1957. In a matter of months the first instrumented earth satellite will be launched resulting in science suddenly falling heir to a tremendous wealth of data concerning radiations from space. For the first time a qualitative and quantitative picture of these radiations will be available to the scientist since the satellite will probe these radiations above the thick turbulent atmosphere which filters, alters and reflects these radiations. It is these radiations, both corpuscular and electromagnetic, which affect the earth and create problems of extreme interest to the scientist who would better understand the electrical layers in the atmosphere.

But as the satellite is not yet a *fait accompli* the scientist must use every other means at his disposal for solution to questions. In this book of some 330 pages, more than four score of the ranking scientists from 18 countries in the field of solar and atmospheric physics have presented their findings. The book is the proceedings of a symposium held under the auspices of the International Council of Scientific Unions Mixed Commission of the Ionosphere. These contributors have tried to draw as definitive a picture of the interaction of solar radiations and the ionospheric layers as is possible at this time.

The scope of the book is covered in an introduction by Dr. J. A. Ratcliffe of the Cavendish Laboratory. In his section he shows how what follows are conclusions drawn from experimental results at times of solar eclipses and how our understanding of the physics of the upper atmosphere here has been aided by this work.

The significance of these experiments may best be understood by realizing that only at the time of a total eclipse of the sun is the entire disk of the sun occulted. With the loss of the radiation from the disk of the sun only that radiation which comes from the outer layers of the solar atmosphere can affect the earth. It is from this radiation and its effect on the atmosphere that scientists expect to learn the mode of operation of all the radiations coming to the earth. As of this moment it has been ascertained that the E and F1 layers are definitely caused by photons. It has been suggested that the same mechanism is responsible for the F2 layer.

In the other eight sections of the book various facets of the problem are examined. The theoretical considerations, the results of the eclipse on the ionosphere, geomagnetic eclipse effects, solar radio noise, etc., are all discussed. Dr. Ratcliffe gives a summary in the last short section of the book.

The editors should be congratulated on the fine collating job. While *Solar Eclipses and the Ionosphere* can serve as a reference book at the moment and should be available to researchers in the field, the book is destined to be short-lived. In the immediate future with the establishment of instrumented satellites, many of the speculative pieces in the

book will be susceptible to definitive answers and at such time this fine book becomes obsolete. It is a pity that the work was published so late. It would be interesting to compare the results which will be forthcoming in the next few years with those in the book.

I. M. LEVITT
Fels Planetarium

WING THEORY, by A. Robinson and J. A. Laurmann. 569 pages, diagrams, 6 × 9¼ in. New York, Cambridge University Press, 1956. Price, $13.50.

It is the stated aim of the authors in presenting the physical and mathematical aspects of wing theory to follow somewhat of a middle course among the variously inclined group of potential readers. In so stating they show full cognizance of the problem facing the advanced reader as being either the one of an engineer, well versed in a knowledge of the physical factors of the subject, whose further advancement depends largely on his adjustment to the need for certain mathematical elegancies; or that of the mathematician, well trained in theories of functions whose basic need might be for a physical "feel" to guide his thinking and to relieve the need for repeated recourse to existence theorems. While engineer and mathematician can to a degree lose their identity in each other at this point, they seem always to retain certain ingrained manners of approach. Thus, while the authors have fulfilled their aim in a very clear style and have provided a text of great value to both factions, they have remained to the mathematical side of their middle road.

To illustrate, the authors discuss very briefly at one point the behavior of a boundary layer in a rising pressure gradient, move quickly into a discussion of a real flow over a flat plate, and allude to the basis for determining the circulation Γ. Later, at another point, lift and lift coefficients for a family of Joukowski airfoils are deduced very neatly and adeptly through use of the complex variable and associated theorems. This, as opposed to the approach where flow over a flat plate is discussed physically at greater length to realize the ultimate resting point of the downstream stagnation point; the study of a circle collapsing (by the same transformation) to a flat plate of chord length equal to four radii, the analysis of the corresponding stagnations in the plane of the circle and intimate dealing with pressure forces in that plane to obtain lift; and then, after all this, to carry on with the authors' discussion.

Certainly the authors could not build up to each subject in such lengthy manner. The illustration is cited only to show what preparation the authors expect the reader to have had or to be separately capable of providing.

In summary, just as Churchill and Knopp present the complex variable in far different, but very complementary veins, so Shapiro and the present authors cover much of the same ground. All four texts are needed. Authors Robinson & Laurmann are to be congratulated on their contribution. The text will be well received by wing designers, those concerned with turbo-machines where the potential theory of the infinite cascade is applicable, and aerodynamicists in general.

F. S. BURRELL
Franklin Institute Laboratories

MODERN MATHEMATICS FOR THE ENGINEER, by Edwin F. Beckenbach. 514 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1956. Price, $7.50.

Modern Mathematics for the Engineer is a compilation of a series of lectures given recently in an extension course in applied mathematics at the University of California, Los Angeles. It is the second work published in a planned series of three. "Modern Physics for the Engineer" preceded the present text. "Modern Chemistry for the Engineer" is expected to follow in about a year. Dr. Beckenbach of the staff of the University of California edited the present book, the contents of which were contributed by 19 authors, each of whom is well qualified in his field.

The techniques of engineering analysis have undergone radical changes during the past decade. Statistical procedures are being more widely applied than ever before. The engineer talks in terms of stochastic processes, power density spectra, and autocorrelation functions. In addition, fascinating new machines are available which reduce computation time from days and hours to seconds, but the engineer must first reduce his problems to terms which can be understood and handled by these machines. The purpose of

the extension course lectures and of the present text is as stated in the preface, "to generate in the minds of engineers and applied scientists engaged in research, design, and administration an awareness of these recent rapid advancements in applied mathematical thought."

To fulfill this aim, the book is divided into three parts. The first, entitled "Mathematical Models," dwells successively on physical problems expressed in terms of ordinary differential equations, integral equations, and partial differential equations. Part two considers "Probabilistic Problems" with chapters on the programming and operational aspects of engineering and on the use of probabilistic methods in solving problems. The final division, "Computational Considerations" deals with numerical solutions and aspects of high speed computing devices. The book is written in a very lucid manner, making the reading surprisingly interesting for a text dealing with such complex subject matter. A rather important feature is a sizable list of references at the end of each chapter including most of the recent papers dealing with the subjects under discussion.

The need for a text such as this is evident. Written in a style that engineers appreciate, it clearly explains both the theory and application of some of the most powerful modern analysis tools available. The authors, men who have made major contributions to the art, and the University of California deserve credit for making the collection available. The book should be welcomed by all whose interests require that they keep abreast with the rapid strides being made in this field today.

D. L. BIRX
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PROGRESS IN SEMICONDUCTORS—1, edited by A. F. Gibson, P. Aigrain, and R. E. Burgess. 220 pages, diagrams, 6 × 9 in. New York, John Wiley & Sons, Inc., 1956. Price, $8.00.

This small volume contains seven papers relating to the increasingly important subject of semiconductors. The term, semiconductors, here applies not only to the metals, germanium and silicon, largely employed in transistors, but also includes phosphors or luminescent solids of the inorganic type. The latter possess the properties of photoconduction and semiconduction as well as certain other characteristics which relate them to this field.

These papers are rather specific in their individual topics. For example, one treats the question of developing high-frequency transistors and the pertinent theoretical considerations. Another deals with the photo-magneto-electric effect in semiconductors. In these papers a summary of findings to date is usually given, followed by some theory in mathematical terms.

Each chapter is the result of separate authorship selected on the basis of international distinction. Consequently, the editors have assumed responsibility as general editor, European, and American in the order given above. It is their aim to publish additional volumes from time to time as significant advances are made. This is an interesting idea, but it is difficult to visualize a scheme which will assure that all of the most valuable papers issue through this publication. The avowed purpose is of course to spare workers in the semiconductor field some of the labor of studying the hundreds of papers which annually appear.

For this summary and the excellent bibliographies which accompany the papers the engineer or physicist may willingly pay the price of these volumes. The success of the "Progress" volumes will depend upon the editors' choices of valuable topics from among the numerous possibilities. Finally, the problem of perpetually locating suitable authors who are willing to prepare the summary type of paper, with all the research that it entails, would seem to present an arduous task with uncertain results. The editors are due considerable credit for attempting such a program.

C. W. HARGENS
Franklin Institute Laboratories

THE CHEMISTRY OF PETROCHEMICALS, by Melvin J. Astle. 267 pages, diagrams, 6 × 9 in. New York, Reinhold Publishing Corp., 1956. Price, $6.50.

More than 25 per cent of all chemicals produced in this country can be classified as petrochemicals—chemicals originating from petroleum. Dr. Astle's volume seems a rather modest size to cover so extensive a field but the reader will find that the text covers

the subject surprisingly adequately in highly readable and systematic style.

Space has been conserved primarily by the author's holding exactingly to the book's title. Several excellent books are available which cover the chemistry and physical properties of petroleum itself, for example, Gruse and Stevens' "Chemical Technology of Petroleum"; Brooks, Kurtz Jr, Boord, and Schmerling's "The Chemistry of Petroleum Hydrocarbons." The present volume takes up where these leave off.

Starting with the synthesis of paraffin hydrocarbons, the author goes into the commercially important chemical reactions as well as those reactions of potential interest which lead to petroleum derived chemicals. Not pretending to be a chemical engineering text, the book nonetheless supplies much of interest to production such as reaction conditions, catalysts used, and special equipment.

Following a brief introduction to the petrochemical industry, Dr. Astle steers the reader to the logical starting point for a book of this scope—the Fischer-Tropsch process. A review of the contents of this chapter is indicative of the ground covered in the body of the book. There is a short history of the process followed by a discussion of the chemistry involved, the raw materials used; products obtained and how they are affected by the choice of catalyst; reaction conditions and their relation to reactants, products, catalysts, and equipment; and, finally, a well annotated discussion of the reaction mechanisms proposed by various chemists.

Proceeding from paraffins to olefins, diolefins, acetylene, naphthenes, aromatics, olefin oxides, alcohols, ethers, aldehydes, ketones, acids, esters, amines, and nitriles, the technical research worker will find a well annotated bibliography supplementing the text in covering the vast but widely scattered literature on petrochemicals.

WILBUR S. HALL
American Chemical Paint Co.

MECHANICS FOR ENGINEERS, by Ferdinand P. Beer and E. Russell Johnston, Jr. 673 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $8.00.

This book is a useful engineering text on mechanics, covering elementary structural analysis and dynamics. The section on Statics deals mainly with the equilibrium of rigid bodies, consisting principally of statical analysis of determinate structures. The introduction of three-dimensional analysis is timely. The presentations of beam theory and section inertia properties are clear. A short discussion of virtual work as applied to rigid bodies with various types of connections terminates the section on statics, Part I. The second part, on dynamics, covers kinematics and the kinetics of elementary rigid body systems. This is followed by the application of work and energy methods for similar problems. The concluding chapter on mechanical vibration is devoted to a complete analysis of a one-degree-of-freedom system, including damping characteristics.

RUPEN EKSERGIAN
Franklin Institute Laboratories

TECHNOLOGY AND ENGINEERING, PROGRESS IN NUCLEAR ENERGY, SERIES FOUR, VOLUME ONE, edited by R. Hurst and S. McLain. 420 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1956. Price, $12.00.

There are six chapters in this book which are in turn subdivided into complete papers concerned with various specific topics relating to the general chapter headings. The first four chapters deal with heavy water, graphite, beryllia, and liquid metals, materials intrinsic to reactor composition. The remaining two chapters are written about engineering and reactor chemistry.

The contents of the several portions of this book are general in character. The information available can be applied to almost any reactor. The detailed description of the methods of production and purification of the materials employed in reactor fabrication would be of great value to those directly involved in reactor production.

Some of the many problems arising on the interior of reactors are treated. These are metallurgical and chemical in character and relate to corrosion, radiation damage, etc. Heat transfer and other thermal aspects of reactors are also treated.

The behavior of aluminum, zirconium and its alloys, bismuth, and bismuth alloys at high temperatures (> 100° C.) is described as well as the properties of the oxides of

thorium and uranium under the conditions encountered in reactor operation.

All of the subjects are thoroughly discussed by experienced authors. It must be emphasized that the content of the book should be of particular interest to those charged with design or maintenance of reactors.

C. E. MANDEVILLE
Bartol Research Foundation

BIOLOGICAL TREATMENT OF SEWAGE AND INDUSTRIAL WASTES. VOLUME 1, AEROBIC OXIDATION, by Brother Joseph McCabe and W. W. Eckenfelder, Jr. 393 pages, illustrations, 6 × 9 in. New York, Reinhold Publishing Corp., 1956. Price, $10.00.

This book covering the aerobic oxidation of sewage and industrial wastes, is a compilation of thirty-three papers presented at the first Conference on Biological Waste Treatment held at Manhattan College, New York in April, 1955. The book is divided into four major parts covering: theory and mechanism of biological waste treatment; aeration—theory and design; sewage treatment; industrial waste treatment.

Part One contains much valuable information concerning the theory and mechanism of biological oxidation. It covers such topics as kinetics of biological oxidation, principles of biological oxidation, equilibria and kinetics of adsorption by activated sludge, factors influencing development of biological flocs, and the application of the logarithmic equation in biological oxidation.

Part Two covers the theoretical and practical aspects of aeration. After the reader hurdles over the mathematics of the first chapter in Part Two he can settle down to some very interesting reading concerning aeration and its principles. Chapter three of this section is particularly informative (aeration and oxygen transport in biological systems—basic considerations) and chapter four covering the effect of oxygen tension is also one of the outstanding chapters in Part Two. The latter part of the second section of the book deals with the design and use of various types of aeration equipment.

Part Three deals with sewage treatment including the design and operation of activated sludge plants, the effect of BOD loadings on activated sludge plant operation, the utilization of the kinetics of activated sludge in process and equipment design, high-rate filters and their application to biological treatment of sewage, and final clarifiers and clarifier mechanisms.

Part Four describes industrial waste treatment and covers the pulp and paper industry, dairy wastes, pharmaceutical wastes, petroleum phenolic wastes, and cannery wastes. The effect of high temperature and high pH on activated sludge is also discussed.

Since each chapter was written by a different author the value of the book must be expressed as the sum total of the value of each chapter. As a whole the book is very well written and should be in the possession of all those interested in bio-oxidation of industrial wastes and sewage. It should be of particular interest to sanitary engineers, chemists, and biologists who have an adequate mathematical background.

FRANK E. MANSON
American Chemical Paint Co.

STATISTICAL MECHANICS. PRINCIPLES AND SELECTED APPLICATIONS, by Terrell L. Hill. 432 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1956. Price, $9.00.

On this text's title page appear the words "Principles and Selected Applications"; these, in essence, describe the particular nature of this volume on advanced statistical mechanics. The first few chapters contain a review of the basic principles while the remaining chapters are devoted to the investigation of specific problems. In this sense the book represents a departure from the standard presentations found in other volumes on the same subject. This is a judicious choice because it allows the author to discuss in detail some problems of present day concern to physicists and chemists without first completely rehashing the fundamental principles which are already very well presented in several earlier volumes by other authors.

As mentioned above, the book is roughly divided into two sections; the first section consists of three chapters; the second of five plus an appendix. Classical and quantum statistical mechanics are discussed separately in the first two chapters and their interrelation in the third. The emphasis in this

latter chapter is on the relation of thermodynamics to quantum statistical mechanics with regard to the particular ensemble used in the description of a thermodynamic system. In the second section, the five chapters are entitled: Fluctuations, Theory of Imperfect Gases and Condensation, Distribution Functions and the Theory of the Liquid State, Nearest-Neighbor Lattice Statistics, and Lattice Theories of the Liquid and Solid States. The appendix contains various examples worked out in detail. The five chapters are a detailed expose of the methods of modern statistical mechanics. Previously, most of these subjects existed as a disjointed collection of papers scattered throughout the literature; however, in these latter chapters the compilation provides a unified discussion of the various topics. Although each chapter is essentially a separate discourse, the exposition often indicates the applicability of a particular method to problems which are considered in other chapters. The over-all character of this second section leans toward the applicational method rather than the deduction of a specific result. In a few cases, this is disheartening, because in wading through the details one occasionally loses the physical meaning in the minutiae of the argument.

The book's most valuable assets are twofold: one, it is a unified approach to the application of modern statistical mechanics to specific problems; second, the examples chosen are of more than academic importance. These reasons alone are sufficient to warrant use of the book as an extension of a course in statistical thermodynamics. There are, however, several unfavorable criticisms worthy of discussion. One of these is due in part to the complexity of the topics considered, and that is, there are, on the average, six numbered equations per page. To the fastidious reader this presents a formidable obstacle; since it makes for very slow reading, and as mentioned above, once in awhile the physical significance of the argument is obscured by the details. Another comment concerns the first three chapters. For someone who is not familiar with statistical mechanics, the beginning chapters are not enough for the complete comprehension of the later chapters. This is not too unfavorable, for as the author points out, the book was not to be treatise on the subject. These latter comments are not forbidding, and in general, the book will be of greatest interest to those who wish to become acquainted with the techniques of advanced statistical mechanics as applied to special problems.

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PUBLICATIONS RECEIVED

The Editors wish to call attention to the following books, received in the JOURNAL office for review. Lack of space prevents publication of reviews.

INTERMEDIATE ALGEBRA, by Paul K. Rees and Fred W. Sparks. Second edition, 306 pages, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $3.90.

INTRODUCTION TO ELECTRICAL ENGINEERING, by George V. Mueller. Third edition, 466 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $7.50.

WISCONSIN'S RENEWABLE RESOURCES, by James A. Larsen. 160 pages, illustrations, 7 × 10 in. Madison, University of Wisconsin, 1956. No price, paper.

FREQUENCY MODULATION, by L. B. Arguimbau and R. D. Stuart. Methuen's Monographs on Physical Subjects. 96 pages, diagrams, 4 × 6½ in. London, Methuen & Co., Ltd.; New York, John Wiley & Sons, Inc.; 1956. Price, $2.00.

ORDER-DISORDER PHENOMENA, by E. W. Elcock. Methuen's Monographs on Physical Subjects. 166 pages, diagrams, 4 × 6½ in. London, Methuen & Co., Ltd.; New York, John Wiley & Sons, Inc.; 1956. Price, $2.50.

MANUAL OF RECLAIMED RUBBER, edited by J. M. Ball. 94 pages, 6 × 9 in. New York, Rubber Reclaimers Association, Inc., 1956. Price, $3.00 (paper).

BOOK NOTES

DOCUMENTATION IN ACTION, edited by Jesse H. Shera, Allen Kent and James W. Perry. 471 pages, 6 × 9 in. New York, Reinhold Publishing Corp., 1956. Price, $10.00.

Based on the proceedings of the 1956 Western Reserve Conference on the Practical Utilization of Recorded Knowledge, this volume gives a detailed and up-to-date review of the organization and utilization of recorded information. The problem of what to do with the mountains of records used in research, engineering, business, government, law and industry is an increasingly vital one. Unless the problems of acquisition, classification and indexing are attacked and solved promptly, our economy will slow down.

The editors are to be congratulated upon their performance of the monumental task of unifying the proceedings (both before and after the conference), editing the various manuscripts into an integrated whole, and particularly for the swiftness with which they were able to get the manuscript to the publisher. Time is important in this field, and the sooner the book's important message gets to those concerned, the better.

The five parts of the book cover: (1) Present Requirements, Methods and Problems; (2) Programs for the Future; (3) Discussion; (4) Cooperative Programs; and (5) Definition of Research Areas. In all, 37 panel talks and full-scale papers and six closed discussions (Part 3) are presented. Many of the authors have contributed to more than one paper. An introduction by J. H. Shera sets forth the problem in a cogent way.

As a cooperative effort involving experts in many fields treating a vital subject, this volume should be studied carefully by all those who are concerned with improving our present out-of-date methods of processing and using information.

ELECTRONIC COMPUTERS, edited by T. E. Ivall. 167 pages, plates, 5¾ × 8½ in. New York, Philosophical Library, 1956. Price, $10.00.

Written primarily for technicians, engineers and students interested in electronic computers, this book will also be of interest to business executives. In non-mathematical language, the contributors treat the broad field of computing in a general way, covering both analog and digital computers. Two introductory chapters on the history and general principles of computing are followed by the main portion of the book—seven chapters on analog and digital computer circuitry, equipment and applications, and one chapter on storage systems. The final chapter discusses "Computers of the Future." The appendix gives a brief discussion of business computer running costs, which should interest the business executive. (Since the book is English, the costs are given in pounds.)

The computers described are all British ones, so the book may be of more interest to American readers as a means of comparing domestic and foreign computers than as an informative discussion.

ADVANCED CALCULUS, by R. Creighton Buck. 423 pages, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1956. Price, $8.50.

A new addition to the International Series in Pure and Applied Mathematics, this text aims to: review elementary calculus without repeating it; present a modern approach to the differential and integral calculus of functions and transformations; develop analytical techniques for attacking problems in applied mathematics; and introduce the student to modern points of view. The elementary theory of Cartan's differential forms is presented herein, although it is usually omitted in standard texts. Over 450 problems are listed and most of their answers are given in the back of the book. The text is intended for a two-semester course and is suitable for majors in mathematics, physics and engineering, either graduate or undergraduate.

THE DIECASTING PROCESS, by H. K. Barton. 224 pages, illustrations, 5¾ × 8¾ in. New York, The Macmillan Co., 1957. Price, $5.00.

Because the technical literature in the field of diecasting has been rather scattered, the author has prepared this book to remedy the

situation. As an international consultant, the author has had wide experience in the field. His book will be welcomed by draftsman and purchasing agents, as well as by those who are directly concerned with machining, electroplating, finishing and assembling diecastings. In addition to covering all phases of diecasting techniques, the book contains ten appendices offering handy information on alloys, machining and polishing recommendations, plating and die specifications, and a series of tables of various properties useful in diecasting.

ELEMENTS OF PARTIAL DIFFERENTIAL EQUATIONS, by Ian N. Sneddon. 327 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1956. Price, $7.50.

This new book gives a practical approach to the theory of partial differential equations rather than general theory. It will be appreciated by mathematicians, physicists and engineers seeking practical aid. Many worked-out examples are included in the text, to help those who are studying without the help of a teacher. The first chapter covers ordinary differential equations, the second chapter treats first-order partial differential equations, and the remaining four chapters are devoted to higher order equations—second order, Laplace's equation, the wave equation and the diffusion equation.

INTRODUCTORY ELECTRICAL ENGINEERING, by George F. Corcoran and Henry R. Reed. 527 pages, diagrams, 6 × 9 in. New York, John Wiley & Sons, Inc., 1957. Price, $7.95.

Based upon Corcoran's "Basic Electrical Engineering," but completely rewritten, this new book is designed as an introductory text to be used either in a short course (first five chapters) or a comprehensive one (8 to 10 chapters). MKS units are used throughout, with secondary units used as necessary. The text stresses circuit analysis and elementary magnetic phenomena, with inductance and capacitance calculations included. The final chapter (10) covers boundary-layer voltages, with a brief discussion of the $p - n$ function, vital to many transistors. The chapters are well illustrated and provide the student with carefully graded problems.

ENCYCLOPEDIA OF CHEMICAL REACTIONS, VOL. VI, compiled by C. A. Jacobson and edited by Clifford A. Hampel. 438 pages, 6 × 9 in. New York, Reinhold Publishing Corp.; London, Chapman & Hall, Ltd.; 1956. Price, $12.50.

Volume VI of this invaluable encyclopedia covers reactions of samarium, scandium, selenium, silicon, silver and sodium. The work of 118 abstractors using 93 journals, these reactions were compiled by the late C. A. Jacobson and edited by Clifford A. Hampel. The series will be completed in succeeding volumes. For each of the six elements covered, the inorganic reagents are printed in boldface type, with a very brief description of the reaction. Each abstract is identified by author, journal, volume and page numbers, and year of publication. Two lengthy indices—one to reagents and one to substances obtained—complete this useful compilation.

MATERIALS AND PROCESSES IN MANUFACTURING, by E. Paul DeGarmo. 755 pages, illustrations, 6¼ × 9¼ in. New York, The Macmillan Co., 1957. Price, $8.50.

This new college text for engineering students is designed to acquaint them with the materials, tools and other equipment used in the manufacture of the end products which, as engineers, they design. The book divides the subjects of materials and processes in such a way that a separate course on manufacturing can be given by omitting Chapters 2 through 8. Five sections divide the text into these main topics: Materials, Casting and Forming Processes, Machining Processes, Welding and Allied Processes, and Processes and Techniques Related to Manufacturing. The book is profusely illustrated with line drawings and photographs. Each chapter has a set of review questions. The Appendix contains a list of 38 reference books, and links each text chapter to several of these references.

CURRENT TOPICS

Closed-Circuit TV System Provides Data on Cancer Cells.—A new application of closed-circuit television that provides immediate comparative data of chemical activity within live normal and cancer cells was reported recently by Arthur L. Malcarney, Vice-President and General Manager, RCA Commercial Electronic Products.

The new technique, made possible by a developmental RCA ultraviolet-sensitive TV camera tube, is undergoing experimental examination at the National Institutes of Health, Bethesda, Md., where it is being used with a high-power microscope and an electronic oscilloscope to obtain direct observations and oscillographic measurements of the metabolism of living cells.

The successful application of ultraviolet television to medical microscopy and oscillographic spectroscopy gives promise of new speed and facility in the analysis of cells and tissue. The system introduces numerous advances in cell research:

1. For the first time, it enables researchers to observe and take motion pictures, simultaneously, of chemical activity within living cells.
2. It makes possible microscopic study and analysis of hundreds of living cells in only a fraction of the time formerly required.
3. It makes possible direct observation and rapid, accurate measurement and identification of certain chemical changes within the cells.

Mr. Malcarney said that the ultraviolet television system utilizes a standard RCA black-and-white TV camera, type TK-21, which is widely used throughout the television broadcast industry. The camera's standard monochrome Vidicon tube has been replaced with the experimental RCA ultraviolet-sensitive Vidicon camera tube. The pickup tube and its circuitry were developed originally at RCA's David Sarnoff Research Center by A. D. Cope and L. E. Flory, under the supervision of Dr. V. K. Zworykin, and furnished to Dr. George Z. Williams for the cell-research program at NIH.

"The RCA ultraviolet closed-circuit TV system," Dr. Williams said, "makes it possible to obtain quick and accurate measurements of ultraviolet absorption in healthy and abnormal cells. The ultraviolet TV camera tube sees more than the eye can discern when living cells are illuminated with visible light. The direct oscillographic analysis and record of any part of the object-image provides immediate comparative data."

Ultraviolet rays, he explained, are absorbed in specific and measurable quantities by different chemicals. This characteristic, he added, enables the medical researcher to: (*a*) identify the nature and scope of several cellular chemical substances by exposing the cell to ultraviolet light and measuring the absorption ratio; (*b*) introduce foreign chemicals and study their reaction with the cell's normal chemicals and, (*c*) by ultraviolet exposure, to maintain serial studies of disease-suspected cells and tissues and detect and identify chemical changes which may develop.

"Heretofore," Dr. Williams pointed out, "the study and observation of

ultraviolet-treated specimens represented a long and laborious process due to the lack of a practical medium for direct observation. The ultraviolet TV camera tube developed by RCA makes practical 'seeing' ultraviolet pictures by television.

"The ultraviolet absorption image, viewed by the TV camera through a microscope, is converted to an electronic signal by the ultraviolet camera tube. The signal is amplified and then viewed on the screen of the TV monitor, a few feet away. Any one of the 525 horizontal scanning lines can be selected and analyzed by a special oscilloscope, which produces on its cathode ray tube, in two ordinates, a tracing of the absorption characteristics of the specimen."

The over-all ultraviolet equipment chain, devised by Dr. Williams, includes an ultraviolet light source, a high-power microscope, the RCA broadcast TV camera with ultraviolet camera tube, a monitor, an oscilloscope, and various motion picture cameras for filming images on both the TV monitor and the oscilloscope.

In operation, the ultraviolet light source is focused on the specimen under the microscope. The RCA camera is mounted so that it "peers" through the eye-piece of the microscope. Sensitive to ultraviolet, it "sees" and transmits to the monitor an image of the cell and the action and reaction of its ultraviolet-absorbing chemicals, both those normal to the cell and those induced artificially or by disease.

"In its present stage of experimentation," Dr. Williams said, "the ultraviolet television-microscope system must be considered as a developmental technique, but one which holds important implications for future medical research. It offers significant possibilities also as an important diagnostic medium, for rapid determination of the nature of a diseased cell by direct ultraviolet TV observation and measurement of the rate, scope, and shape of abnormal chemical changes."

Electric Tension Indicator.—All tension meters known to date show tension visually only. Now a novel electrical contacting device calls the attendant by the flashing of an electric light when tension goes above or below pre-set limits of best operation in textile, wire, and rubber mills. The device is manufactured by Tensitron, Inc., of Harvard, Mass.

Mounted upon an insulating cover, a U-shaped holder on top of a tension meter holds two tension setting screws with special contact points. They can be adjusted so that the lever tilting between them makes contact at any desired tension. Connected to the sensing lever in between them travels an electric contact, the position of which is determined by the tension. Filaments are guided over the rollers of the electric tension indicator. A warning light flashes if tension falls below or exceeds the limits of best running conditions.

A transparent cover protects the contacts. They are free from arcing due to a special circuit. The instrument is free from indefinite contacting and contact burn-out, despite standard 115-volt operation. All electrical connections are inside a small switch-box. On one side of this box is a flexible cable which feeds a clearly visible indicator lamp, to call maintenance personnel.

The electric tension unit is small, light in weight, and can easily be attached from the holes in its handle to any type of frame.

Atomic Radiation Spurs Growth of "Whiskers" on Metals.—Atomic

radiation spurs the growth of hairlike metallic strands—called "whiskers"—on metal, it has been found by Bell Telephone Laboratories scientists. More than five years ago the Bell System's research and development unit found that microscopic metal "whiskers" had literally grown on some types of telephone equipment and had caused short circuits. The discovery of the metal whiskers opened a new avenue of scientific research and thousands of tests were made at Bell's Murray Hill, N. J., Laboratory.

Recently, Bell Laboratories has grown small, needle-shaped synthetic crystals of germanium and silicon, materials widely used in transistors and other tiny electronic devices. These and other whisker-like crystals have been demonstrated to possess great stength.

Some time ago Bell researchers wondered if the samples of metals they had been testing for whiskers would behave in the same way if they were exposed to bombardment by neutrons in a nuclear reactor. Samples of tin were placed in the reactor at the Brookhaven National Laboratory and removed a month later.

Examined recently after a year of "cooling off," the irradiated samples were found to have grown more whiskers than identical ones on shelves, in ovens and in cold chambers at Murray Hill. Metallurgists explain that damage to the crystal structure of the metal caused by the neutron bombardment had increased the tendency to produce the minute filaments.

The fact that metal whisker growth is greatly accelerated by radiation will be studied further by many scientists concerned with metals. The test of the effect of atomic radiation, latest of an extensive series conducted by S. M. Arnold, Bell metallurgist, is but one part of Bell Laboratories' general program of metal whisker research.

With the increased use of tiny electronic parts likely in the telephone industry and elsewhere, whiskers could cause short circuits between minutely spaced metal surfaces. Telephone scientists know that design of new electronic equipment must take into consideration the whisker-growing potentialities of various metals.

X-ray studies have been made of the atomic or crystal structure of whiskers. These reveal the "crystal direction" in which whisker growth takes place on certain metals. Knowledge of this will help scientists to understand how to grow or retard the growth of whiskers.

The whiskers on some metals do not grow large enough to be seen through an ordinary microscope, and an electron microscope provides the only way of determining their growth. On other metals which grow large whiskers, the electron microscope detects sprouting before the whiskers are large enough to be seen through an ordinary microscope.

While whisker growth is a new field of research, there have already been tangible results in the form of recommendations concerning the use of some metals.

Bell Laboratories scientists found whisker growth on platings of zinc, tin and cadmium used as finishes in telephone apparatus. In critical Bell System circuit applications where whiskers could cause short circuits, these platings have been discontinued and non-whisker sprouting metals have been substituted.

Gold plating was recommended for use instead of tin in the repeaters of the transatlantic telephone cable, which just went into commercial operation. In extensive tests, gold had been found to be whisker-free under operating conditions.

Whisker-proof plating metals are used in the metal "can" assembly of the transistor, the tiny amplifier invented at Bell Telephone Laboratories.

Whisker research really began with a specific case of trouble-shooting on a long distance telephone circuit. The culprit was found to be in a device called a "wave filter," important in making possible dozens of conversations simultaneously over a single telephone circuit.

One of the filter's components, a capacitor, had developed an unexplained "ground." An alert engineer scrutinized the capacitor in a strong light with a magnifier. Something glinted. What looked like lint, but much finer, connected a "hot" terminal of the capacitor to a nearby mounting bracket $\frac{3}{16}$ of an inch away, which was "grounded."

The tiny strand had conducted to "ground" the electricity that was intended to carry voices. Investigation showed that the zinc-coated bracket had grown electrically conductive whiskers.

The questions of what makes whiskers grow, and what they consist of, have since occupied many researchers, at Bell Laboratories and elsewhere. More than 3000 samples of metals are now being treated at Murray Hill to determine whether they will produce whisker growths under various conditions.

When more is known about the growth, structure and physical properties of whiskers, it may be possible some day to apply this knowledge in making metals far superior in strength and durability to today's metals. One of the most interesting facts about the whiskers is that their strength far surpasses the strength of the material from which they sprouted. This was shown in 1951 by C. Herring and J. K. Galt of Bell Laboratories.

Dr. William B. Meldrum (1887–1956).—The JOURNAL records with deep regret the death of one of its valued Associate Editors, Dr. William B. Meldrum, on December 31, 1956. Born in Canada, Dr. Meldrum attended McGill University for his Bachelor's and Master's degrees; he received his doctorate from Harvard in 1914, in physical chemistry. He taught at Vassar College for three years before going to Haverford College in 1917, where he became Head of the Chemistry Department in 1926—a position he held until ill health forced his retirement in June, 1956.

Dr. Meldrum was a frequent contributor to chemical journals and was the author of several college chemistry texts. He was active in several scientific organizations, including the Chemical Society, the Electrochemical Society, the Science Teachers Association (of which he was President in 1927), and the New England Association of Chemistry Teachers.

Dr. Meldrum was appointed an Associate Editor of this JOURNAL in January, 1938, and continued this work until a few weeks before his death. His passing leaves a vacancy which will be difficult to fill, for during his long association with us, he never failed to perform promptly the tasks assigned to him. Our Associate Editors are responsible for maintaining the high standards of this JOURNAL; to Dr. Meldrum, posthumously, we offer our sincere thanks for a job well done over a long period of years.

Hermetic Seal Terminals.—International Resistance Co., Philadelphia, now offers miniature units for superior hermetic sealing of all types of

electrical components. Known as Type LT, the terminals are designed to meet all military and commercial application requirements.

A body of molded Fluorocarbon Plastic* insulates the solder seal ring from the feed-thru lead. Type LT's are unaffected by high humidity and are chemically inert to organic solvents, acids, alkalies, oils and fumes. Physically tough, they will withstand usual production handling and will not crack or craze. They successfully overcome electrolysis under high DC voltage, low corona breakdown voltage, low operating temperatures, inconsistent hermetic seals and similar limitations often found in other types of hermetic sealing terminals.

The IRC Type LT Terminal is specifically designed for requirements such as superior insulation resistance, zero moisture absorption, high arc-over resistance, wide temperature range and thermal shock, and miniaturization.

Transistor Pocket Radio.—A new ultra miniature four-transistor pocket radio has been recently put on the market by Gardiner Electronics Co. of Phoenix, Ariz. This little radio is the size of a package of cigarettes 2⅞ in. × 2 in. × 1 in. and weighs only 3½ oz. including the battery. It comes equipped with a hearing aid type earphone. It has a loud clear tone and is so powerful that using only an 8-in. wire for an antenna it has brought in radio stations over 1000 miles away at night. It runs on only one small flashlight battery that will last 600 hr.

Computing Facility for Project Vanguard.—The Navy Department has announced that an IBM 704, most advanced of the high-speed electronic computers manufactured by International Business Machines Corp., will calculate and predict the orbit of the unmanned satellite to be launched by Project Vanguard during the International Geophysical Year (IGY). The satellite will be fired from Patrick Air Force Base, Florida, sometime during the IGY, which begins July 1, 1957 and continues through December 31, 1958.

It was announced also that Dr. Paul Herget, a consultant to the Naval Research Laboratory, will head the staff of the Vanguard Computer Center to be located in Washington, D. C. Dr. Herget, Director of the Cincinnati Observatory and Professor of Astronomy at the University of Cincinnati, is noted for his work in keeping track of some 1600 minor planets for the International Astronomical Union and has rediscovered the orbits of several which have been lost from view for decades. Much of this work was done with the use of electronic computers.

The IBM 704 will be installed in the Vanguard Computation Center to be located in Washington, D.C., for preliminary tests and dry runs well in advance of the launching data. As the satellite is carried into space by a three-stage rocket, the Vanguard computer will go into 24-hr.-a-day action to predict the course of a 20-in. sphere whose visibility 300 miles above the earth has been compared to that of a golf ball dropped from a supersonic jet plane at an altitude of 60,000 ft.

The task is an enormously complicated one. Keeping ahead of the fast-moving satellite calls for the timetable which is influenced by the laws of celestial mechanics. A circle or ellipse representing the satellite orbit can be drawn through fixed points in space only. It will not

* Polymonochlorotrifluoroethylene.

rotate with the earth, whose surface will shift 1600 equatorial miles to the east in the hour and a half required for the satellite to complete a 360 degree spin around the world. Unlike an aircraft, the tiny sphere will be free of our atmosphere at heights ranging from 200 miles and up. The result will be a man-made moon rising in the west and setting in the east approximately fifteen times a day over successive areas of the planet from which it was launched.

The computer must accurately chart the satellite's course in advance no matter what orbit is selected. Equipment in the instrument-packed 20-in. sphere will emit a radio signal to be picked up as the satellite passes each of the strategically located radio tracking stations. The system employed is known as "Minitrack," which takes its name from the miniature transmitter to be carried by the satellite. Within twenty minutes, three sets of data, each consisting of two angles of measurement plus time of measurement, will be relayed from the Minitrack station to the Vanguard Communications Center in Washington, D. C., and thence via Teletype to the Vanguard IBM 704 installation.

Immediately, the giant machine will process these data at electronic speeds. The results of the computations will be transmitted back over the Teletype to the Vanguard Communications Center. From there they will be flashed to alert the Minitrack station next in the path of the satellite.

Present plans call for the official tracking stations to be located at the following sites: Blossom Point, Md. (40 miles south of Washington, D. C.); Fort Stewart, Ga.; Batista Field, Havana, Cuba; Coolidge Field, Antigua Island, British West Indies; Mt. Cotopaxi, Quito, Ecuador; Ancon, Lima, Peru; Antofagasta, Chile; Peldehue Military Reservation, Santiago, Chile; and Navy Electronics Laboratory, San Diego, Calif.

IGY observation points will be given the time and elevation of passage, and angular velocity. The latter is especially important, since an optical station must know both the direction and speed beforehand in order to fix the satellite in the telescope sights as it appears, traverses the skies swiftly from west to east, and disappears below the horizon in a few minutes time. The satellite will move across the sky, at the rate of about a degree per second, that is, it will appear to move a distance equivalent to the diameter of the moon in about half a second.

In making its orbital calculations, the computer relies principally on a high-speed magnetic core storage or "memory" by which the machine is programmed to act on the input data in accordance with a set of recorded instructions. Individual magnetic cores are about the size of a pinhead and shaped like a dough nut with a hole in the center. Thousands of cores are strung on a complex of wires in such a fashion that several wires pass through the center of each core. Combinations of electrical impulses on these wires alter the magnetic state of the tiny cores. A line of cores, some magnetized, some still neutral, stands for a certain number or word in much the same manner as dot-dot-dot dash-dash-dash dot-dot-dot spells out SOS in Morse code.

Up to 32,678 of these words can be stored in the magnetic core "memory." Another 32,678 words can be held in auxiliary storage by attaching two magnetic drum units, and the 704 can also control ten magnetic tape units with a capacity of 900,000 words each.

Any word in core storage can be transferred from the memory to the arithmetical unit for processing in 12 millionths of a second. Seventy per cent of the arithmetic calculations that take place are executed at the rate of 41,700 per second. Such high speeds are of prime importance in engineering and scientific problems. In most cases, this means a tremendous saving in valuable man hours. In the case of the earth satellite, however, the high speed of the computer is especially important since the satellite's flight can be traced by the tracking station for only one or two minutes in most cases, depending on the satellite's altitude.

The ability of the machine to keep track of a decimal point automatically through myriad and intricate calculations is another invaluable feature. For example, in the split second it takes the sound from a radio loudspeaker to travel across a room, the 704 can multiply two ten-digit numbers fifty times, placing the decimal point correctly in the result each time.

Mathematicians have already begun to devise various programs for the 704, all aimed at predicting the satellite orbit as accurately as possible. Generally, each program is first punched into cards and then transferred onto magnetic tape in a card-to-tape converter. Thus, the machine memory can be quickly erased and tape-fed a new set of instructions at the rate of 2500 words per second.

Among the programs to be developed is one which will operate on observations made near the firing site, as the rocket reaches third-stage burnout and ejects the satellite in space. These early data will be computed to determine whether the satellite has attained a good orbit—one which will not bring it so close to the earth as to be destroyed by atmospheric friction.

A second program, to which the 704 will then be switched immediately, will make calculations on reports received from the earliest Minitrack observations. There will also be a complete program to refine the orbit after sufficient observations have been made to predict the course of the satellite more accurately. In fact, this refining process is characteristic of the over-all computer function.

The lightweight Minitrack batteries in the satellite will last only a relatively short time. When the radio signal stops, IGY scientists will have to rely on optical observations alone. For this reason, an exact satellite timetable becomes even more important as the artificial moon continues in its orbit. Without the 704, it is possible that the satellite would be lost in space in short time.

Iron-Dust Magnets.—Working with invisible iron "dust," General Electric researchers have created a revolutionary and potentially super-strong magnet. Dr. T. O. Paine, of the company's Instrument Department at Lynn, Mass., told the American Association for the Advancement of Science that the unique properties of this magnet are achieved by precisely controlling the size and shape of individual iron particles so small that there are more than a billion billion in a pound.

Speaking at the annual Citation Dinner, sponsored by the Industrial Science Section of the AAAS, Dr. Paine said that, theoretically, the ultra-fine particle iron magnet can be made ten times stronger than the best available magnets. Already experimental magnets have been made equal to the strongest commercial magnets, he added.

"The new magnet," E. E. Parker (General Manager of the Instrument Dept.) said, "will result in electric instruments that are smaller, lighter, more accurate and more rugged, making possible significant advances in instrumentation. It will help us make better photographic exposure meters, aircraft instruments and other products using permanent magnets.

"Although it will be quite some time before the new magnets are commercially available, the door is now open to new magnet applications as significant as those that followed General Electric's introduction of Alnico—the most important permanent magnet material now in use.

"This development opens whole new vistas to the design engineer because the iron particles can be embedded in plastics, metal, rubber or glass. The magnets are easily machined, drilled, tapped, soldered, and molded precisely into any desired shape.

"Ordinary iron is used in the form of sub-microscopic elongated particles to make the new magnet. This leads to another far-reaching benefit, the saving of strategic metals like nickel and cobalt—heavily used in making most magnets. Elimination of cobalt makes possible the application of magnets in nuclear reactors, where magnets containing cobalt cannot be used because of high induced radioactivity."

Dr. Paine and his group faced a seemingly insurmountable obstacle in the development work. How could they control the shape of iron particles finer than the smoke from a cigarette, smaller than the wave length of light, invisible under a conventional microscope, so small that there are more than a billion billion in a pound?

Experiment after experiment failed. Then finally the "break-through" came. They produced a few particles with significant elongations. The most powerful electron microscopes—through which the iron "dust" can be seen—confirmed these results and subsequent experiments brought full success.

"The magnetic and mechanical properties of this material can be controlled precisely," Dr. Paine said. "Not only can the qualities of available magnets be duplicated, but we can achieve characteristics previously unattainable."

High Speed Printer-Plotter.—An ultra high speed printer-plotter device that can translate the lightning fast language of an electronic computer into easily read printed records as fast as the "brain" can calculate is being successfully used at Aberdeen Proving Ground, Md., to process ballistic missile test data.

Believed to be the first "read out" device to match the speed of a computer, the printer-plotter was developed by Burroughs Corporation for the Ballistics Research Laboratories under an Army Ordnance Contract. It is known as BEPOC (Burroughs Electrographic Printer-Plotter for Ordnance Computing).

BEPOC was designed as part of an automatic data handling system capable of accepting the high speed output of a computer directly. Ordinarily computer information is "read out" through a buffer, such as a magnetic tape storage system, that holds the information until conventional printers can print it.

Used in connection with ORDVAC, the Proving Ground's Ballistic Research Laboratory computer, BEPOC actually operates as a high speed page printer in translating the computer's words into printed plotting positions and alphameric information on con-

tinuous rolls of ordinary page-width paper at a speed of 300 plotting points per second.

On test in the laboratory at Aberdeen since last June, BEPOC also automatically prints legends and graph lines while translating and printing ORDVAC's output. Reproduction of the BEPOC record is obtained by using translucent paper and ordinary blueprint machines.

BEPOC is a general purpose data recording device that, according to laboratory experts, has exceeded requirements. It is one application of an electrographic recording technique as developed by Dr. Herman Epstein, Burroughs research scientist. A laboratory model of the device has printed 5000 characters per second serially in tests.

BEPOC uses a three-stage operation to produce its printed record. Characters, plotting positions and alphameric information first take the form of a pinpoint pattern of electrostatic charges on the surface of low-cost paper as they come from the computer.

Next, the pattern is made visible by passing the paper through a dry ink bath. Tiny amounts of the ink cling to the electrically charged pinpoint areas. The paper then rolls across a temperature controlled hot plate that "fixes" the ink permanently, making it fade proof and smudge proof.

The pinpoint pattern is made by passing short bursts of electric current through selected wires in a small matrix. Selection of the proper wires forms successive character or numerals. Each image is formed on the paper in three-millionths of a second.

Gold for Insulation.—Atoms of pure gold are being used experimentally at Ford Motor Company in Dearborn, Mich., to insulate automobile windshields and window glass against summer heat rays. Ford research engineers say that when glass samples are coated with a gold film 30,000 times thinner than a human hair, they filter out the sun's heat-producing rays but allow cooler beams of light to pass. Light insulating experiments also are being conducted at Ford's Scientific Laboratory with silver, aluminum, zinc, copper, vanadium, tantalum, titanium and uranium, as well as with minerals having unusual optical properties.

Ford researchers place gold foil and a sample of glass plate in a bell jar and then pump a vacuum in the jar comparable to that in a common radio tube. Then they melt gold electrically inside the bell jar. The gold "evaporates" in the vacuum and sprays atoms in all directions at speeds above 5,000 miles an hour. This puts a gold coating on the glass plate. While the atomic bombardment coats the glass, a light meter continuously measures the amount of light passing through the glass. The meter halts the depositing process before the coating becomes heavy enough to affect the transparency of the glass plate.

Ford engineers say the coating process is halted when the deposit of gold atoms is one thousand times thinner than a machinist's micrometer can measure.

New Electronic Memory Unit.—A new memory device that will enable electronic computers to store more than a million bits of information in a space little larger than a shoe box and to recall any or all of the items in a few millionths of a second has been announced by the David Sarnoff Research Center of the Radio Corporation of America.

The new memory, consisting bas-

ically of thin, printed plates of special magnetic material perforated with small holes, was developed by a research group under the direction of Dr. Jan A. Rajchman, RCA scientist who also developed the RCA high-speed magnetic core memory system used in many present-day computers.

Announcing the new unit, Dr. Irving Wolff, Vice-President, Research, of RCA, stated that it "opens the way to major advances in efficiency in electronic computers and data processing systems."

"A key point in the operation of all electronic computers is the information storage system in which various elements of a computing problem are stored electronically and recalled instantly as they are needed," said Dr. Wolff. "The development by Dr. Rajchman of the magnetic core system several years ago brought substantial gains in speed and efficiency by providing for the first time a means for storing thousands of bits of information and recalling them instantly in any desired order, combination, or quantity.

"The new apertured plate now carries this development several steps further, providing a means for handling millions rather than thousands of bits of information, and at the same time offering far greater compactness and operating simplicity than could be achieved with the earlier system. Moreover, the new device lends itself to extremely simple molding production techniques, in contrast to the relatively complex process of threading thousands of tiny cores onto a wire matrix to produce the magnetic core device.

"This development should permit the design and construction of larger and more versatile electronic computers and data processing systems, and it will at the same time provide a compact and economical type of memory for relatively small computing equipment."

Information is Stored in Magnetic Form

Explaining the new device, Dr. Rajchman pointed out that its operating principles, like those of the magnetic core system, are based on the fact that computer language consists only of "0" and "1," used in various combinations to represent any words, numbers or symbols.

"Since any desired information can be formulated in terms of 0 and 1, it is possible to employ a storage or memory system in which each of the memory elements can be switched electrically to represent one or the other of these two values," Dr. Rajchman explained.

"The new aperture plate memory stores this information in the form of magnetic fields. One of the two values is represented by a flow of magnetism, or magnetic flux, in one direction around a hole in the plate, while the other value is represented by a magnetic flux in the opposite direction."

According to Dr. Rajchman, the small plates used in the new system are made of a special RCA-developed ferromagnetic material, a ceramic-like substance that can be molded in any desired size or shape, and hardened by heating. The technique of fabricating these plates was developed by C. Wentworth, of the RCA Laboratories technical staff. The experimental units produced at the David Sarnoff Research Center are less than an inch square and contain 256 holes, permitting the storage of 256 bits of information in each plate.

Dr. Rajchman pointed out that production of the presently-used magnetic core memory system involved a

complex assembly operation, since it was necessary to thread wires in two directions through tiny ferromagnetic cores, and then to link all of the cores in a system with two more windings. The row and column windings in the core system served to address each individual core, while the other windings provided the means for storing and reading out information.

"With the new plate system," said Dr. Rajchman, "the plates themselves are insulators and the holes can be joined by conductors using the highly efficient printed circuit technique in place of the complex storage and readout windings of the previous core system.

"The development of these aperture plates has now reached a stage which opens possibilities of memories of very large capacities—millions of bits. Because this arrangement requires much less driving power than previous systems, it promises also to reduce and simplify the associated electronic circuits. Furthermore, it makes possible very compact memories of relatively small capacity."

In illustration, Dr. Rajchman displayed a compact memory plate unit consisting of ten plate assemblies and a novel switch also made from the plates. This developmental unit, measuring only 2 cubic inches, has a storage capacity of 2560 bits of information.

"Three years ago, it was predicted that micro-second memories with capacities reckoned in millions of bits would be available at a relatively low cost in a distant future," Dr. Rajchman said. "We believe that the ferromagnetic aperture plate is now ready to usher in this era. But the demand for larger and faster memories is incessant, and we may look forward to the development of still newer techniques in the future, making possible the storage and instant selective readout of billions of bits."

"Packaged" Water Plant. — A "packaged water plant" capable of satisfying emergency water requirements of 50,000 people has been developed by sanitary engineers at the U. S. Army Corps of Engineers' Research and Development Laboratories, Fort Belvoir, Va.

The plant, which can purify water up to rates of 12,000 gal. per hour, can be operated by one man. Now undergoing troop tests by Fort Belvoir's Engineer Test Team of the 79th Engineer Construction Group, it is producing drinking water from the polluted Potomac River.

Designed for field erection, the plant consists of three main all aluminum sections . . . an "Erdlator" and two gravity type sand filters. The Erdlator, a cone shaped up-flow coagulation basin 14 ft. in diameter, removes mud, bacteria and other suspended matter from the water and makes effective disinfection and filtration possible.

When the raw water enters the Erdlator, it is aerated and then thoroughly mixed with the coagulant, ferric chloride; the coagulant aid, pulverized limestone; and the disinfectant, calcium hypochlorite. Subsequent flow through the clarification zone permits agglomeration of the chemical precipitates and the colloidal particles in the water, and the hydraulic separation of the resultant slurry. The coagulation process is continuous and is accomplished in approximately 20 minutes. Excess slurry is continuously withdrawn, concentrated, and discharged to waste.

Effluent from the Erdlator is discharged to two open type gravity sand filters operated in parallel. The

filter effluent is collected in a bolted aluminum water storage tank for subsequent pumping into a pipe distribution system.

It is expected that the plant will be used at hospitals, prisoner of war camps, air bases and at various other installations.

Housed in a 40 ft. × 40 ft. building, it is the largest in the family of water purification units developed by the Laboratories' Sanitary Engineering Branch to meet field requirements. Rounding out the family are an airborne trailer-mounted unit rated at 600 gph and truck and skid mounted versions which can purify 1500 and 3000 gal. of water per hour. All units operate on the same principle.

Significant in their development were Harry N. Lowe, Jr., chief of the branch; Richard P. Schmitt, chief of the development section; and C. H. Spaulding, consultant. Development of the package plant has been accomplished by M. Raul Rodriguez, Lt. John S. Jeris and Mr. Joseph Mancuso of the Sanitary Engineering Branch.